

CHAPTER 6: SPACECRAFT ANTENNAS

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6.0 INTRODUCTION (STUDY OBJECTIVES AND TRADE-OFF CRITERIA)

In the previous report on spacecraft antennas for the Personal Access Satellite system [1], we identified, in a very general manner, various categories of issues that must be considered in the selection and design of spacecraft antennas for such a communication satellite system. Here we consider some of those issues in more detail and provide parametric studies for some of the antenna concepts to help the system designer in making the most appropriate antenna choice with regards to weight, size, complexity, etc.

The question of appropriate polarization for the spacecraft as well as for the User Terminal antenna required particular attention and was studied in some depth. Circular polarization seems to be the favored outcome of this study.

Another problem that has been generally a complicating factor in designing the multiple beam reflector antennas, is the type of feeds (single vs. multiple element and overlapping vs. non-overlapping clusters) needed for generating the beams. This choice is dependent on certain system design factors, such as the required frequency reuse, acceptable interbeam isolation, antenna efficiency, number of beams scanned, and beam-forming network (BFN) complexity. This issue is partially addressed, but is not completely resolved. Indications are that it may be possible to use relatively simple non-overlapping clusters of only a few elements, unless a large frequency reuse and very stringent isolation levels are required.

6.1 PARAMETRIC STUDIES: NUMBER OF BEAMS, GAIN, SIZE, AND WEIGHT

For the coverage of the Contiguous United States (CONUS) a closed form relation was derived that relates the number of beams, N , to the half-power beamwidth of the multiple beam antenna, BW , in degrees. It is given as

$$N = 17.5 / BW^2$$

This equation is based on the solid angle of the coverage region as seen from the satellite and is valid as long as the satellite is in the geostationary orbit at approximately 90 to 100 degrees West Longitude. This relation is graphically presented in Figure 1. Several specific coverage cases were considered and the actual number of beams is also presented in the figure. As can be seen the agreement is quite good, especially for smaller beamwidths.

The actual number of required beams starts to increase for larger beamwidths, since in this case it is hard to match the beam footprints to the contour of the boundary and the area covered by beams becomes larger than the required coverage region. Since

$$BW \approx 70 / (D/\lambda),$$

we can also write

$$N \approx (d/\lambda)^2 / 280$$

Figure 1 also provides the required antenna aperture diameters for the 20 and 30 GHz frequencies corresponding to the various beamwidths.

As for the weight of the antenna system, we concern ourselves only with a reflector antenna system. A full aperture array system is in general too heavy and complex to be considered for this type of application. The weight of the reflector and the support structure depends on the actual implementation and will be discussed in Chapter 7. Here we confine ourselves to the study of the feed array weight for the reflector system. A fixed multiple beam antenna is assumed.

The feed array dimensions depend, in general, mainly on

- i) the angular dimensions of the coverage region, and
- ii) the focal length of the reflector system.

The feed array dimensions are practically independent of

- i) the frequency or wavelength of the operation, and
- ii) the number of beams over the coverage region.

Of course, since the focal length is typically of the order of the reflector diameter and should be larger for a larger number of beams, the size of the array becomes indirectly dependent on the reflector dimension, the number of beams and the frequency. A more complete discussion of these issues can be found in Reference [2]. These observations are used in deriving the following formulas for the feed array weight.

The array weight, W , is given by

$$W = S W_a + N W_{TR}$$

in which S is the surface area of the array feed given by

$$S = \{(1/b)(F/D)[1+(h_c/4F)^2]\}^2 D^2 \Omega$$

F is the focal length, D is the reflector diameter, b is the beam deviation factor and approximately equal to or less than unity, h_c is the offset of the reflector center from the main axis (zero for a symmetric configuration), and Ω is the solid angle of the coverage region given approximately by

$$\Omega \approx 0.006 \text{ Steradian.}$$

Then for $b=0.9$ and $F/D=1.5$, S is approximated as

$$S \approx D^2/60$$

N is the total number of beams, W_a is the weight per unit of feed area, and W_{TR} is the weight per unit TR module. The latter is based on the assumption that due to the considerable loss in the beamforming network, the feed corresponding to each beam will have its own TR module which consists of a diplexer, a high power amplifier (HPA) and a low noise amplifier (LNA), if the same antenna is used for both transmit and receive operations. The number of the modules could be larger than the number of beams if a more complex feeding system such as an overlapping cluster concept, in which adjacent beams share in a number of radiating elements, is employed.

Of course for separate transmit and receive antennas only an HPA or an LNA will be needed, and the corresponding weight, W_{TR} , will be reduced.

Finally, the overall feed weight can be approximated by either

$$W \approx 4.8 N \lambda^2 W_a + N W_{TR},$$

as a function of the number of beams, or

$$W \approx (D^2/60) W_a + (1/280)(D/\lambda)^2 W_{TR},$$

as a function of reflector diameter. Figure 2 presents a graphical representation of this relation for the transmit and receive antennas. In this figure we have assumed, based on prior experience and the study of a number of cases, that

$$W_a \approx 1.5 \text{ Kg/m}^2, W_{TR} \approx 0.1 \text{ Kg.}$$

Naturally, for specific cases one should make the appropriate changes in the above values for more accurate results.

6.2 ANTENNA POLARIZATION TRADE-OFF (CIRCULAR VS. LINEAR)

An important factor in the design of the PASS system is the choice of the electromagnetic field polarization for the antennas. The design of the spacecraft as well as of the ground user antennas will be affected by this choice. At Ka-band frequencies Faraday rotation in propagation through the atmosphere is not a concern. Therefore, ideally, the linearly polarized antennas should be selected, since this choice simplifies the design of the feeding networks.

However, due to the selection of a multiple beam spacecraft antenna, the linear polarization, at different beam footprints on the ground, will present different levels of cross polarization. This can be seen clearly in Table 1 which presents the variations in the polarization directions from the ideal vertical polarization, at different locations on the ground. This table is based on a program which can solve for any general case in which spacecraft antenna may have any desired position and orientation and can be directed toward any given point on the ground.

The spacecraft feed array can be designed in such a way that the radiating elements for each beam will be polarized differently in order to achieve the best polarization quality within that beam footprint on the ground. However, if for any reason the spacecraft is moved to a different geostationary position, it is possible that the beam polarizations may deteriorate unacceptably.

The movements of the user antenna on the ground may also complicate the situation by not matching the polarization presented by the spacecraft antenna.

The circularly polarized antennas are more robust, however. They are more forgiving of the vagaries of the user antenna movements, and far less sensitive to the relocation of the spacecraft antenna to different geostationary positions.

Appendix I discusses some of these issues in more detail.

6.3 FEED DESIGN TRADE-OFF (OVERLAPPING VS. NON-OVERLAPPING)

The design of the feed and beamforming network for the reflector is perhaps the most challenging aspect of the spacecraft antenna design. This design will affect the overall antenna gain loss, the achievable sidelobe levels which have a direct bearing on the interbeam isolation levels needed for a frequency reuse operation, as well as the polarization of the antenna. This issue has been studied before and documented in [2]. Appendix II provides some additional insight into the choice of simple or multiple element overlapping cluster feed. Overall, it can be said that the choice of the simple non-overlapping feeds is more desirable in most cases.

There are, however, instances in which due to the requirements of a very large number of beams, very low sidelobes, high interbeam isolation, and very large frequency reuse, the introduction of the overlapping cluster design may become necessary. This is particularly true when far scanned beams in a very large multiple beam system will have unacceptably high coma lobes which can be cured by the implementation of a multi-element feed array and/or a much larger focal length/reflector diameter ratio, F/D .

A specific trade-off issue is the choice between a reflector system with a very large F/D and hence large feed array and support booms, or a complex and heavy beamforming network for the overlapping feed clusters. This issue needs further analysis in the context of more specific requirements of the system.

6.4 ALTERNATIVE DESIGN OPTIONS

In this section some alternative design issues are considered. One issue relates to the selection of the most appropriate optics, namely, the number and type of the reflectors and feed arrays and their configuration. A second issue relates to the multiple beam construction and operation and whether they are fixed, switched, or scanned.

And, finally, the issue of beamforming network design in respect to the mechanics of the power distribution is considered and discussed. The beamforming network can be designed to optimize the efficient use of the power amplifiers under conditions of short or long term variable channels allocation and usage by different beams covering different geographic regions.

6.4.1 ALTERNATIVE REFLECTOR/FEED TOPOLOGIES

The last PASS report [1] enumerated some alternative design concepts for the reflector system configuration. The simplest design involves the use of a single offset-fed reflector with a focal plane feed array for fixed simultaneous multiple beam operation. Some numerical results for this design are presented in the next section. Here we look at two alternative concepts.

A promising system involves the use of a near field array in conjunction with a single hyperbolic (as opposed to a typically parabolic) reflector which provides for beam scanning by varying only the phase of the component feed elements (Reference [3]). A theoretical computer study of this concept has been undertaken, but no concrete results have been obtained so far. By using a multi-layer beamforming network (BFN) one can achieve a multiple beam system with independently scanned individual beams with only a single reflector and feed array. We recommend that this concept be further studied in the future since it may be one of the more attractive advanced concepts in the reflector RF design.

Another option considered was mechanical beam scanning by using a small movable array in conjunction with a symmetric parabolic reflector or a spherical reflector antenna. The spherical reflector has the advantage that once the excitation values are evaluated for the on-axis beam, the same excitation values can be used for off-axis or scanned beams, due to the rotational symmetry of the reflector. The results of the mechanical scanning study are presented in Appendix III.

6.4.2 SCANNING / SWITCHED BEAM VS. FIXED BEAM TRADE-OFF

In multibeam satellite systems, scanning/switched beam concepts may be used instead of fixed simultaneous beams. This can reduce the number of components and the weight of the system at the expense of requiring more complex components and beam management systems. The following is a description of the major features of switched or scanned beam systems.

Switched Beams:

- 1- The number of active beams at any given time is fewer than the total number of beams needed for the entire coverage region.
- 2- The number of required feed array elements is the same as that needed for a fixed multiple beam system.
- 3- The number of high power amplifiers (HPA) and low noise amplifiers (LNA) is reduced.
- 4- To provide the same number of channels as a fixed multiple beam system, using a time division multiplex system, higher power HPAs are required.
- 5- The system requires complex switching networks including PIN diodes and/or ferrite switches and their driving circuitry.

Scanned Beams:

- 1- As in the switched beam case, simultaneous coverage is not provided for the entire coverage region.
- 2- Can be used in a single or dual reflector system with a phased array feed (see section 6.4.3).
- 3- The number of required feed array elements, if a single reflector antenna is used, is more or less the same as that needed for a fixed beam system.

- 4- The number of required feed array elements can be substantially reduced if a dual reflector antenna system is used.
- 5- The number of HPAs and LNAs are reduced.
- 6- To provide the same coverage as a fixed multiple beam system, higher power HPAs are required.
- 7- The HPAs and the LNAs may require wider bandwidths.
- 8- Requires the use of variable (continuous or multiple-bit digital) phase shifters in the beamforming network.

6.4.3 INTERBEAM POWER MANAGEMENT

Multiple beam systems can increase transmission capacity with an increase of satellite antenna gain and reuse of allocated frequency band. However, the implementation of a multiple beam system for contiguous communication requires special considerations to avoid inefficient use of satellite power and to ensure reliable operation. For single beam systems, all the transponders are connected to a single beam, and every Earth station has access to all the transponders. Therefore, traffic variations in a local area are acceptable, provided they do not exceed the total transmission capacity.

On the other hand, in the case of multiple beam systems, the area subtended by each beam is only a part of the total service area, and the transmission capacity of each beam is also a fixed portion of the total transmission capacity. Thus, the fixed allocation of transponder capacity to each beam degrades the flexibility of the system under varying traffic distribution.

In order to cope with these problems, two adaptive schemes are suggested in this section. One is the multiport Hybrid transponder that can be used for a multibeam antenna system, where each beam is generated by separate feed array elements. The other is a full array beam forming network, where each beam is generated by all the feed array elements.

(a) Multiport Hybrid Transponder:

This system, as originally proposed by Egami et al. [4], consists of multiple hybrids and multiple amplifiers and inherently realizes wide-band transmission. Figure 3 shows a 4-port Hybrid transponder where each 4-port box depicts an ordinary 90 degree hybrid. When all the amplifiers are working properly, the information in each beam ends up in one of the antennas only.

Meanwhile, every beam is amplified by all the amplifiers and, therefore, failure of one amplifier does not cause the total loss of that beam's transmission. Hence, this scheme allows for graceful degradation of the multibeam system if one or few of the active elements fail. Moreover, since the amplifiers share a common wide frequency band, the number of carriers transmitted from each beam can be changed from 0 to maximum value, limited only by the total transmitting power. Therefore, this system provides the adaptability needed for the efficient use of satellite power.

Figure 4 shows the 4-port Hybrid transponder used with an offset parabolic antenna system for a simultaneous fixed multibeam transmission. In this configuration, the feed array is placed on the focal plane of the reflector and the reflector is in the far field of the feed array. The hybrid transponder sends each of the beams to a separate feed array element, in the focal plane, and generates the corresponding far field pattern of the reflector.

The disadvantage of this system is that it requires many 90 degree hybrids which increases the size of the feed array assembly. However, it does not need complex phase shifting components and the associated circuitry.

(b) Full Feed Array Beam Forming Network:

In this concept every beam is generated by all the feed array elements. Figure 5 shows a 4-beam, 4-antenna element system. Each beam is connected to the elements of the feed array via phase shifters. The phase shift provided by each phase shifter is determined precisely to point each beam in a specific direction. The amplifiers share a common wideband and each contributes to the amplification of all the beams. Therefore, the failure of one amplifier does not cause a total failure of a beam but only a graceful degradation in the system performance. This concept, like the hybrid transponder method, allows adaptive carrier allocation to each beam. The number of carriers in each beam can change from zero to the maximum, limited only by the total transmission power.

Figure 6 shows two reflector antenna configurations that can be used with the full feed array beam forming network. In Figure 6-a, a single hyperbolic reflector is used in the near field of the feed array [3]. With the feed array outside of the reflector focal region, it is possible to generate multiple far field beams from the multibeam near field pattern of the feed array.

Figure 6-b shows a dual parabolic reflector system where the subreflector is located in the near field of the phased array. In both systems, by proper positioning of the array such that the center of the main reflector and the array are conjugate points, an optimum design can be achieved such that among other things, the reflector surface deformations can be compensated solely by the phase adjustment of the array elements [5].

This system does not require the large number of hybrids which are needed for the hybrid transponder. However, it requires a large number of phase shifters which are relatively complex, lossy and costly.

6.5 DESIGN DATA FOR SELECTED ANTENNA SIZES

For PASS, two separate multibeam satellite antennas are used for receive and transmit to alleviate the potential problem of passive intermodulation (PIM). In order to provide the required antenna gain of over 52 dBi, antenna diameters of the order of 2 to 4 meters at the uplink (receive, frequency of 30 GHz) and 3 to 6 meters at the downlink (transmit, frequency of 20 GHz) are considered.

These antennas produce beams with 3-dB beamwidth of approximately 0.35 degrees for the 2/3 meter system and 0.175 degrees for the 4/6 meter system. Therefore, to cover the CONUS it is necessary to scan the feeds in these antennas by either 10 or 20 beamwidths for the 2/3 or 4/6 meter systems, respectively, as shown in Figures 7 and 8 (reproduced from [1]). Scanning the beam off axis will cause performance degradations which include loss of gain and higher sidelobe levels. However, the severity of these degradations is a function of the reflector geometry and the feed illumination of the reflector.

In this section a parametric study is performed to evaluate the effect of the satellite antenna F/D and the feed edge taper (ET) on the antenna gain and pattern as the feed is scanned. The geometry of the antenna and the location of the feed are shown in Figure 9. In this study two antenna sizes (2 or 4 meters in diameter) are considered at 30 GHz. For the 3 and 6 meter antennas at 20 GHz, the same results will apply since their electrical dimensions (i.e., in terms of the wavelength) are the same. respectively.

To cover the entire CONUS, the feed has to be scanned in both x and y directions as shown in Figures 7, 8, and 9. However, the required scan in the y direction (here assumed to be the East-West direction) is much larger and causes a more severe pattern degradation than in the x direction. Therefore, only the results for the feed scanned in the y-direction are presented here.

The results reported here are generated using a reflector antenna computer program based on the application of the physical optics integration which is evaluated by the Jacobi-Bessel expansion technique [6]. This computer program generates the far field pattern of reflector antennas, with given geometrical dimensions, based on the location and pattern of their feeds.

Table 2 shows the on and off axis gain and efficiency of the 2-meter antenna, as a function of the reflector (F/D) and the feed edge taper, when its feed is scanned in the y direction by 10 beamwidths (the maximum scan in the East-West direction as shown in Figure 7).

Table 3 shows the same parameters for the 4-meter antenna when its feed is scanned in the y direction by 20 beamwidths (the maximum scan in the East-West direction as shown in Figure 8).

As expected, in general, larger F/D (or F , since D is fixed) and higher ET values improve the off-axis gain and efficiency of the reflector, and reduce the sidelobe degradation. However, the larger the F is, the longer and heavier are the supporting booms and the larger is the size of the feed array (see Section 6.1 and References [2] and [7]). Moreover, the values of the ET larger than about -5 dB require overlapping cluster feeds instead of simple feeds.

Overlapping cluster feeds require much more complex beam forming networks (BFN) and are also heavier. Therefore, it is important to keep the ET under -5 dB and the focal length as small as possible.

Figures 10 through 17 show the far field patterns of the 2- and the 4-meter antennas when their feeds are either on focal point or scanned by 10 or 20 beamwidths, respectively. All the patterns are normalized to the on-focus beam maximum and are plotted about their maximum without making corrections for the beam deviation factor. With these figures, the degree of pattern degradation and gain loss can be compared for different values of F/D and ET .

By analyzing the data shown in Tables 2 and 3 the following can be concluded:

For the 4-meter antenna, the supporting boom for the feed has to be very long to avoid high gain loss and poor efficiency. An F/D of 2 requires a focal length of 8 meters for the 4-meter antenna and 12 meters for the 6-meter antenna, focal lengths which are prohibitively large. For an F/D of 1.5, it is necessary to have an $ET = -15$ dB or higher, which still requires long feed support structures as well as a very complicated BFN.

For the 2-meter antenna, an F/D of 1.5 can be used with an $ET = -5$ dB to obtain acceptably low gain loss, moderate size for the feed supporting structure, and a simple BFN. For higher ET values, low gain loss and high efficiency can be achieved at the expense of requiring a more complex BFN.

6.6 CRITICAL TECHNOLOGIES AND DEVELOPMENT GOALS

The major challenging technologies for the PASS satellite antennas are described below.

(1) Monolithic Microwave Integrated Circuit (MMIC)

The large feed arrays needed for the satellite antennas require very complex electronic circuits. These circuits must be low loss, low weight, and compact in size. MMIC manufacturing technology is a key to implementing such circuits and, therefore, must be developed for use in this system.

(2) Overlapping Cluster Feeds

Overlapping cluster feeds are needed to generate closely packed (high cross-over) multiple fixed beams with low sidelobes. This requires developing either MMIC or RF/Optical/RF beamforming networks for the 20/30 GHz region.

(3) Low Loss Phase-Shifters and Power Dividers/Combiners

In order to generate time scanned beams, the feed array beam forming network requires phase shifters and power dividers/combiners. At 20/30 GHz frequencies, low loss phase shifters and power dividers/combiners present a formidable challenge and need to be developed using MMIC technology to achieve efficient beam scanning.

(4) Low Loss Switching Networks

In order to generate switching beams, the feed array beam forming network requires switching circuits to activate a desired group of radiating elements for each specific beam. Low loss switching networks for 20/30 GHz frequencies are very complex and challenging to develop.

(5) Time-Delay Beam Forming Networks

In order to generate scanning beams across the coverage area using the frequency scan approach, true time delay elements (such as filters), in which the phase changes linearly as a function of the frequency, are needed. Development of beam forming networks employing these components is a challenging task.

(6) Adaptive Reflector Distortion Compensation

To compensate the effect of the time varying thermal and dynamic distortion on the reflector system in space, adaptive feed arrays can be used. Techniques for compensation of these distortions, by real time change of the array elements phase and amplitude, should be investigated and evaluated for technical feasibility and cost.

(7) Efficient Feed Array Elements

Low loss, wideband, and efficient array elements, capable of providing large scan angles, are needed to avoid overall antenna performance degradation. New concepts in array element technology such as scanning or stacked elements should be investigated and their feasibility studied.

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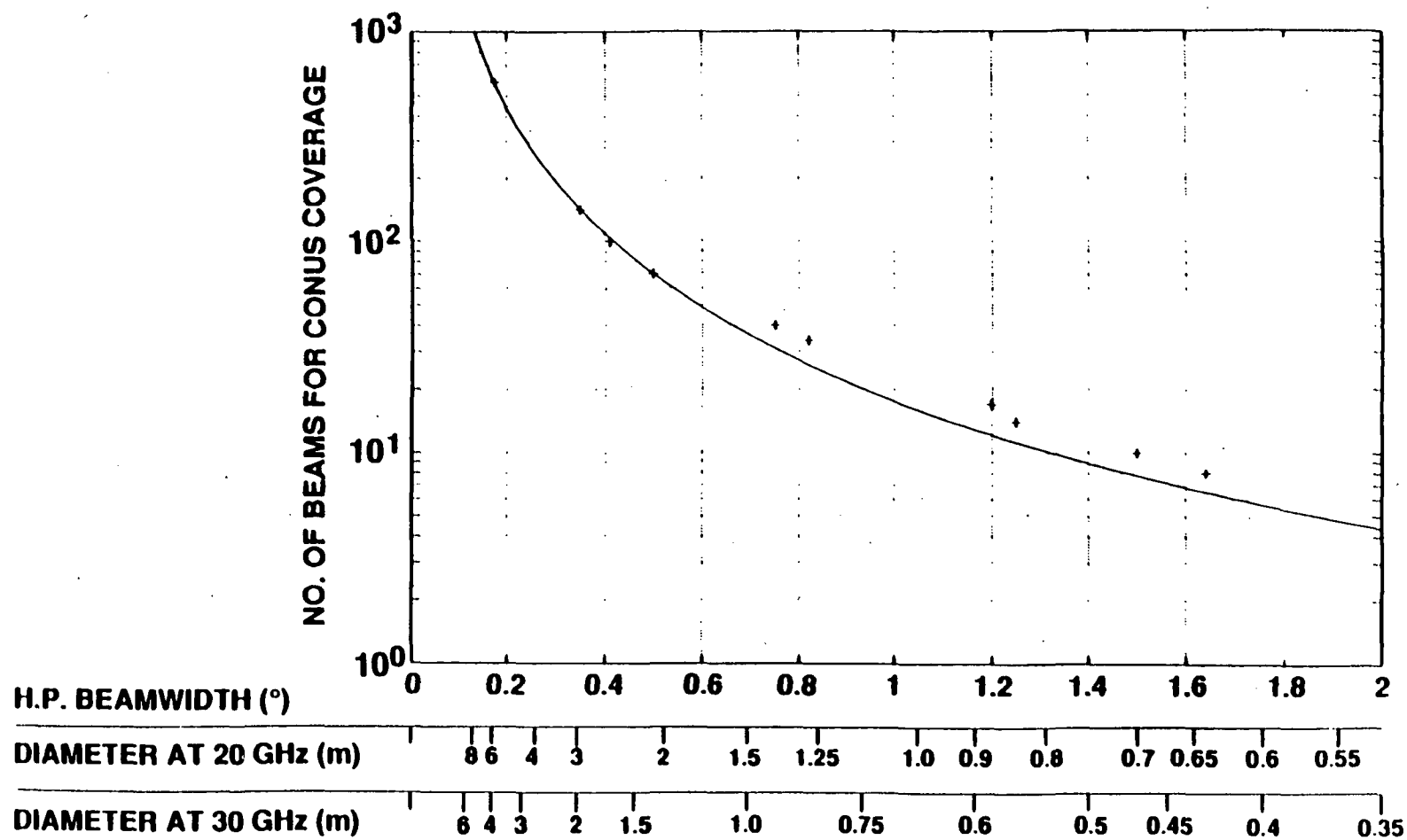


Figure 1. Number of beams as a function of beamwidth for multibeam CONUS coverage.

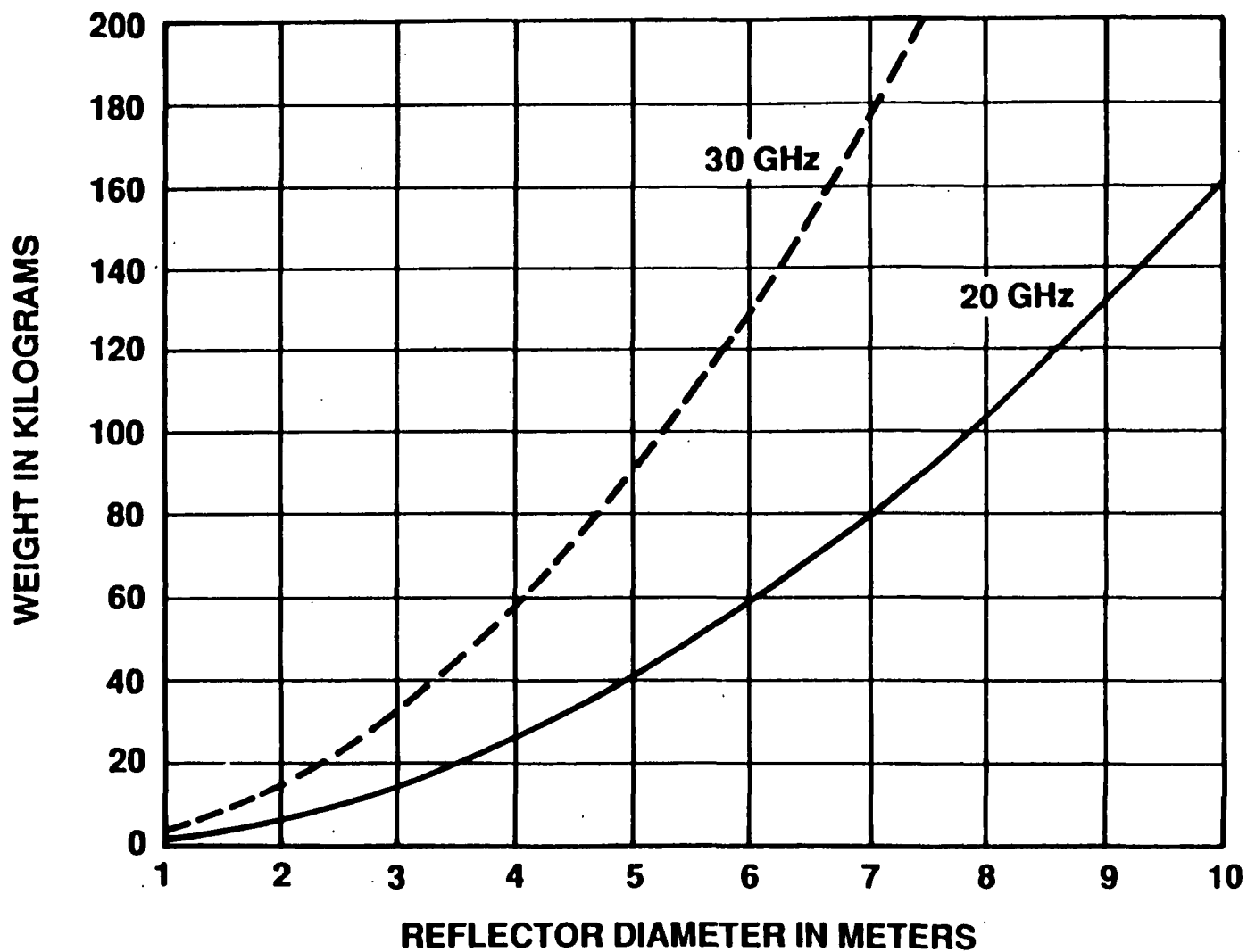


Figure 2. Spacecraft feed array weight as function of reflector diameter for multibeam CONUS coverage.

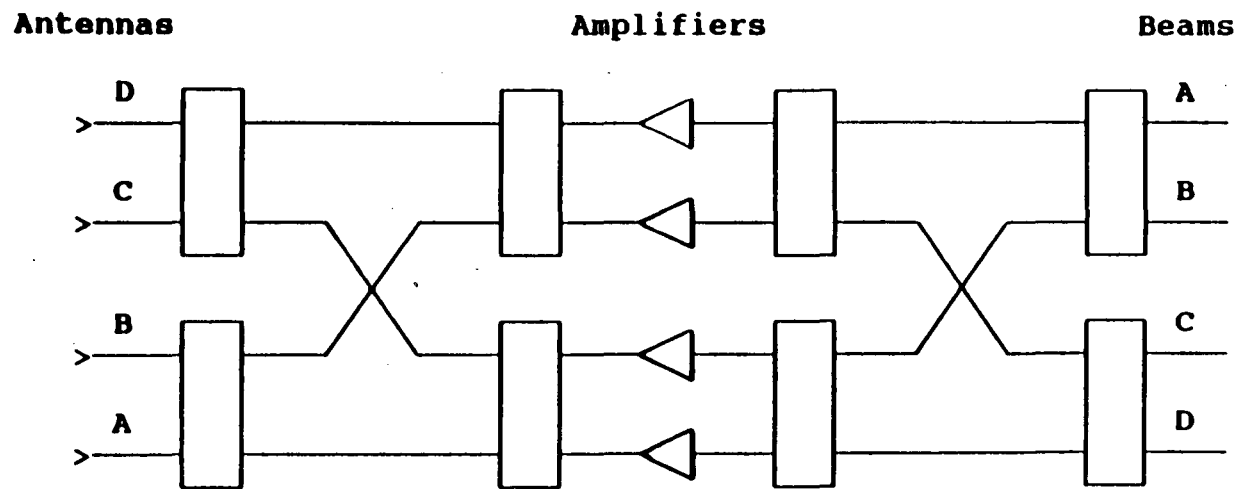


Figure 3. Configuration of a 4-port hybrid amplifier.

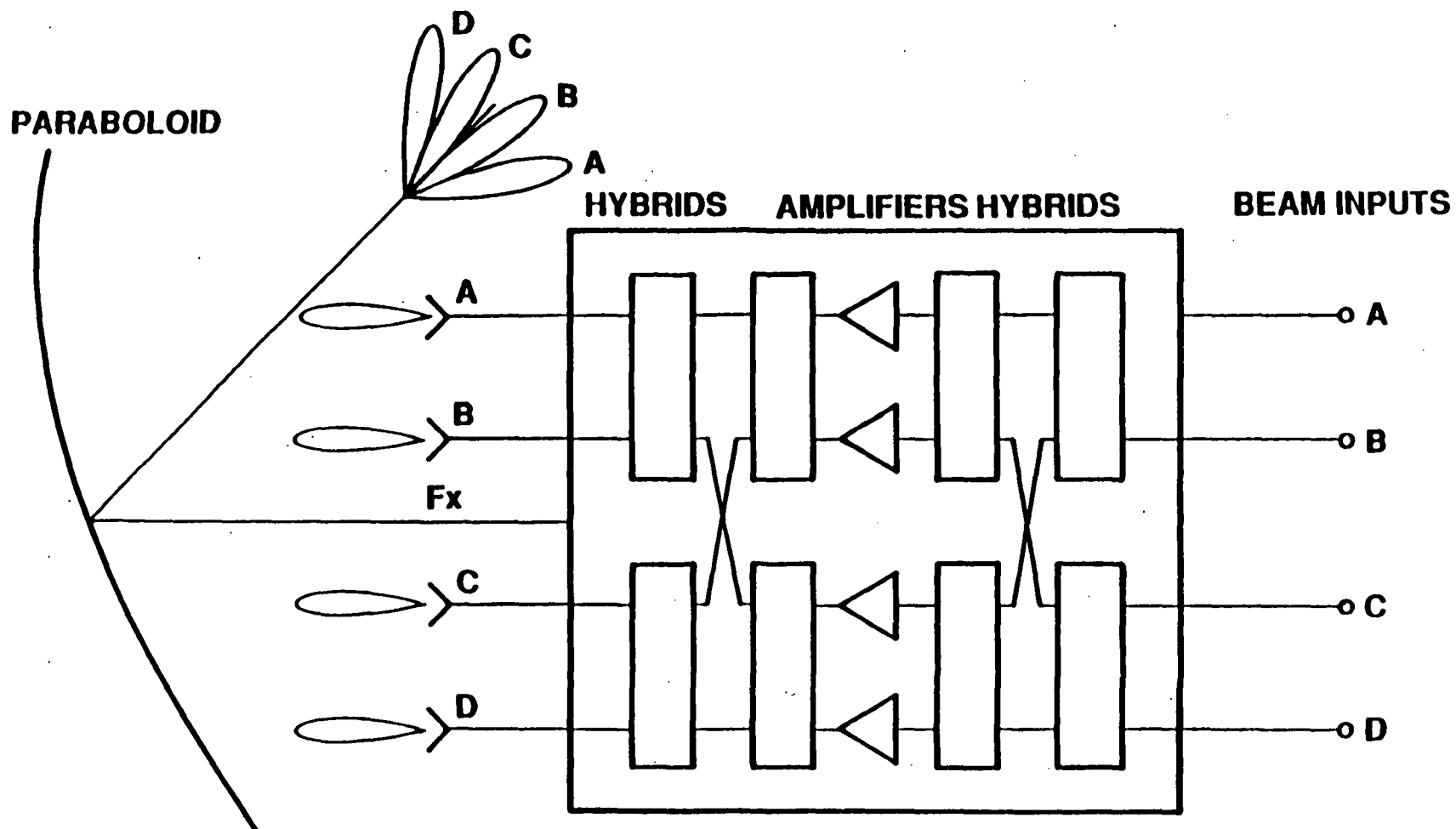


Figure 4. Hybrid multibeam amplifier concept: Each beam is produced by a separate feed but shares in all the amplifiers.

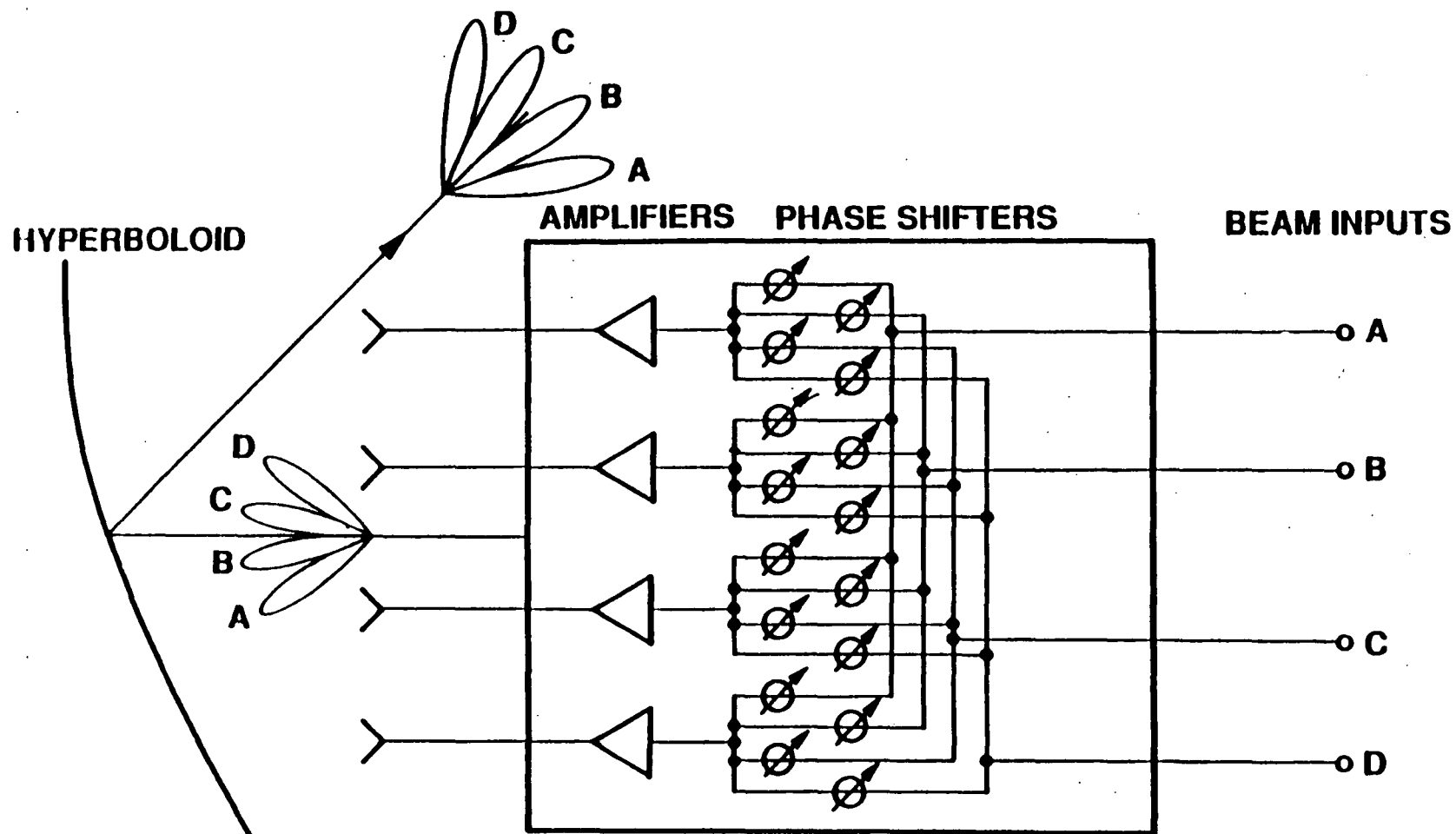


Figure 5. Near-field phased array concept: Each beam is produced by all the feed elements and shares in all the amplifiers.

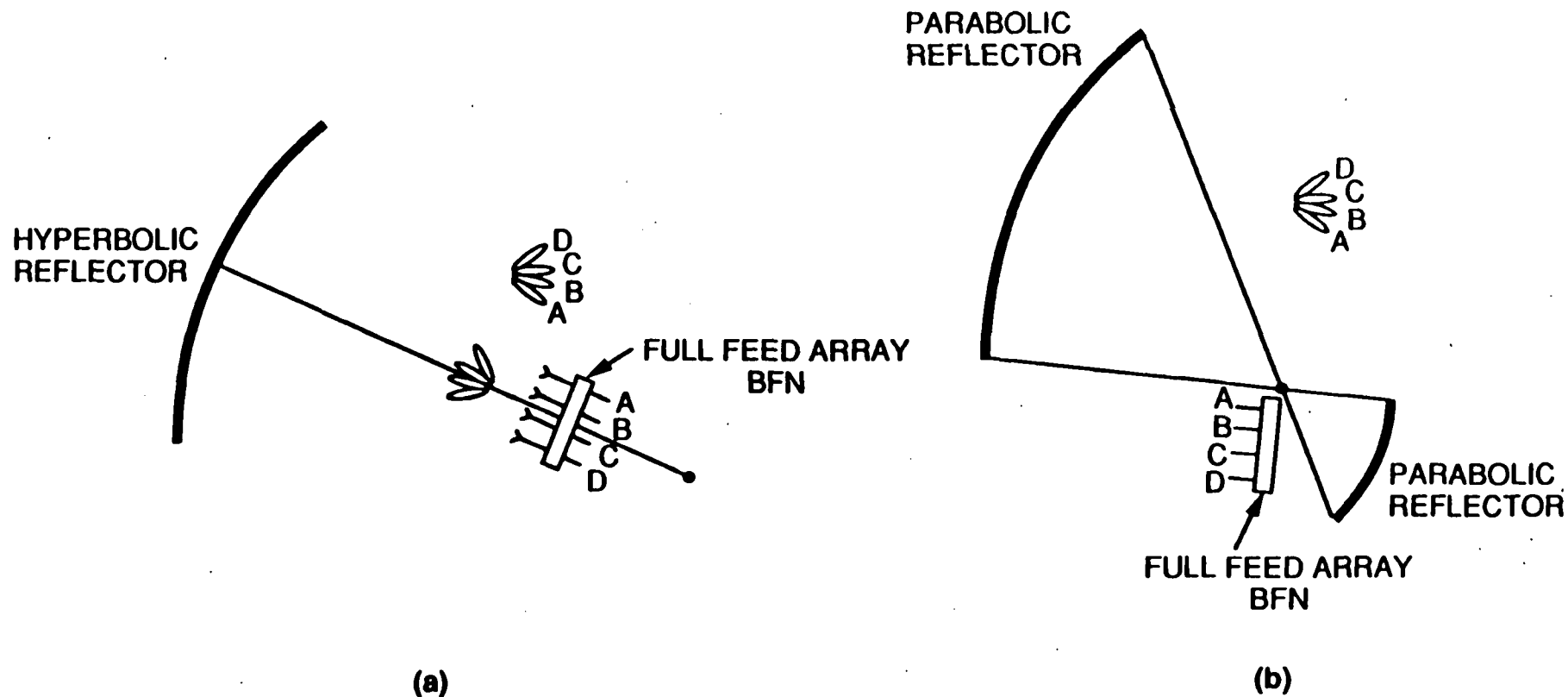


Figure 6. Simultaneous fixed multibeam antenna using full aperture feed array to provide each beam. a) Single hyperbolic reflector with phased array, b) Dual parabolic reflector with near-field phased array.

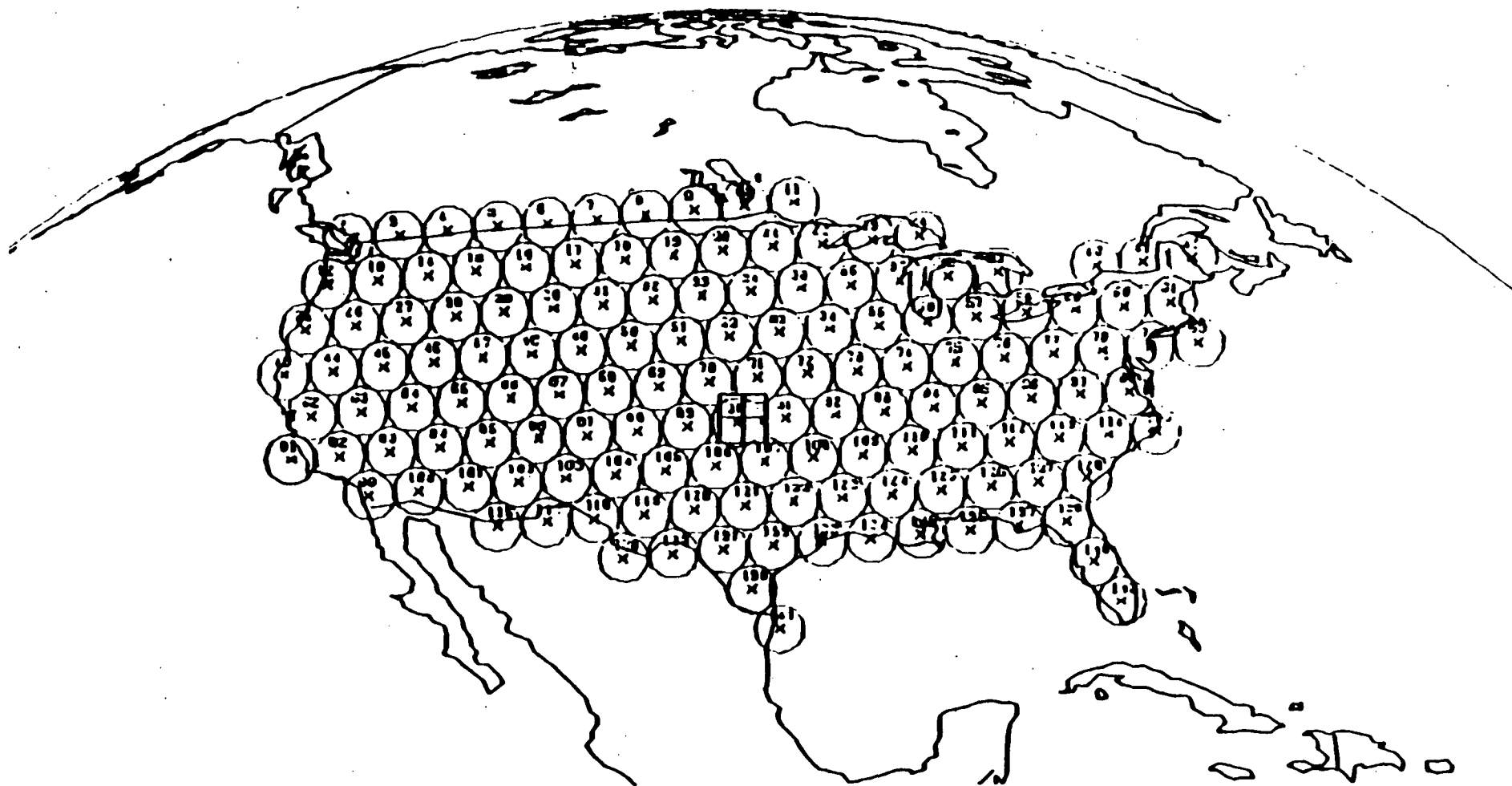


Figure 7. CONUS coverage with 142 spot beams with 0.35° half-power beamwidth using a 2-meter diameter antenna at 30 GHz or a 3-meter antenna at 20 GHz.

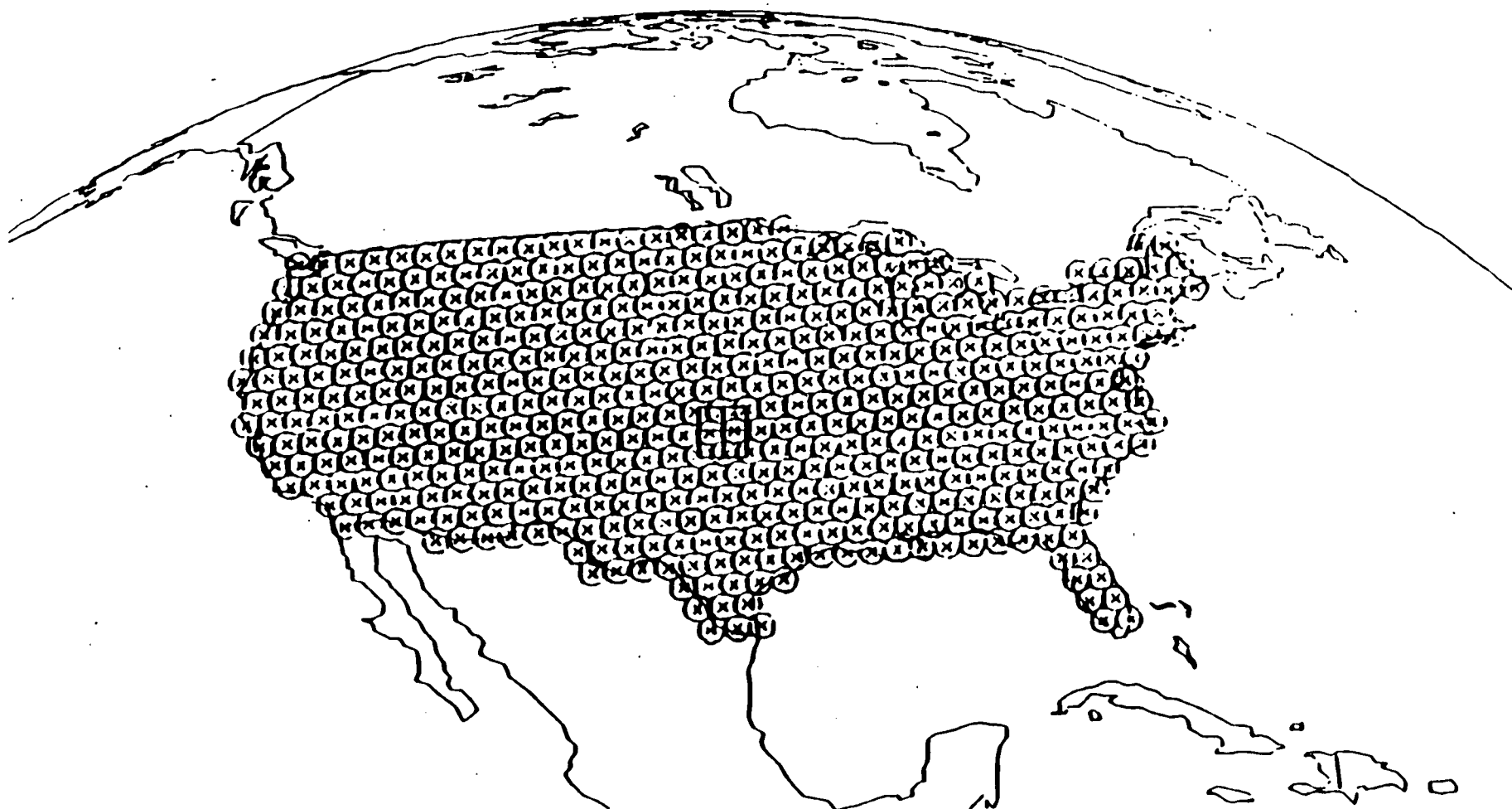


Figure 8. CONUS coverage with 582 spot beams with 0.175° half power beamwidth using a 4-meter diameter antenna at 30 GHz or a 6-meter antenna at 20 GHz.

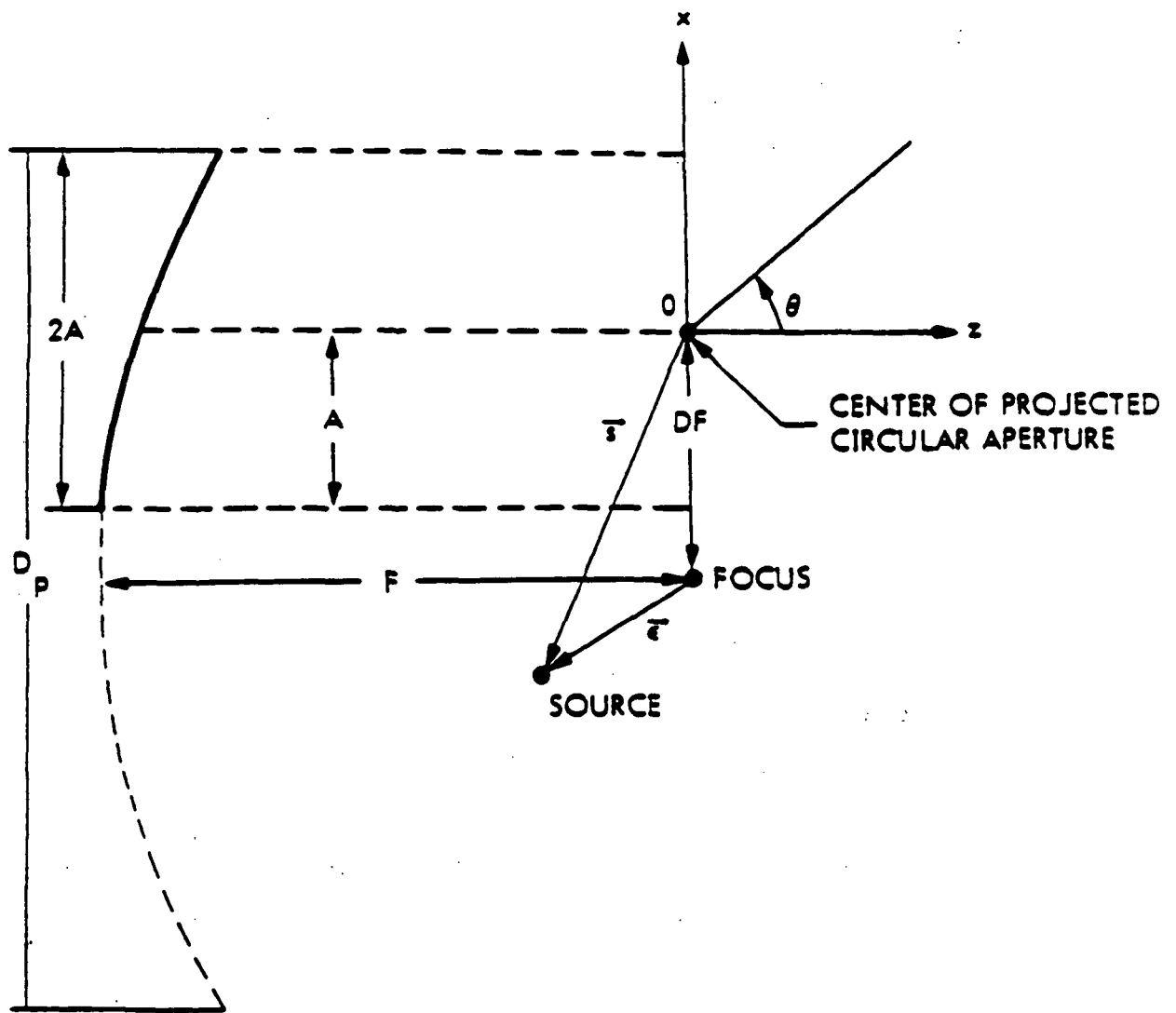
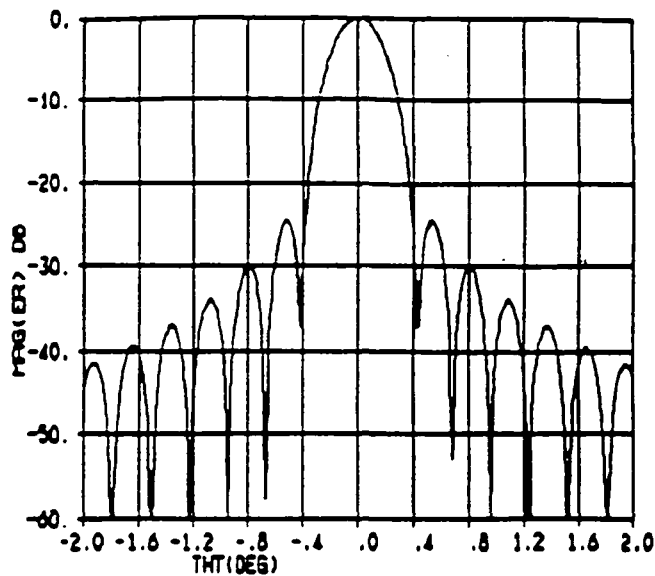


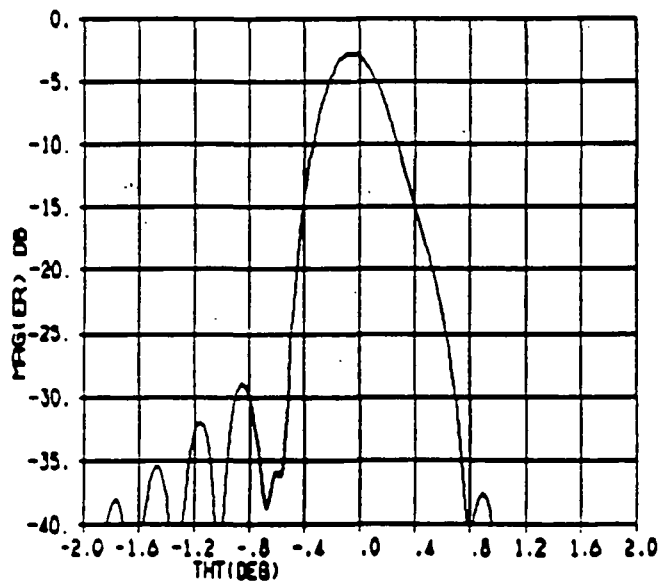
Figure 9. Offset parabolic reflector geometry.

2-M PASS REFLECTOR FEED ON FOCUS, PHI=0., ET=-10, F=2



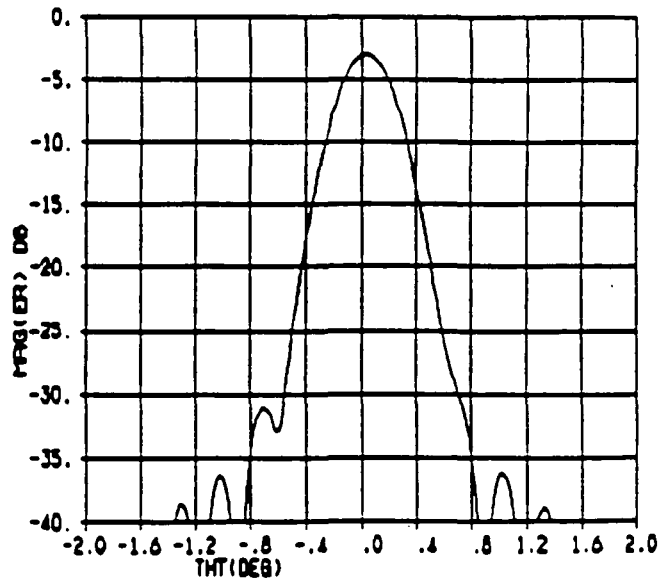
(a)

2-M PASS REFL SCANNED IN Y DIR., PHI=0., ET=-10, F=2



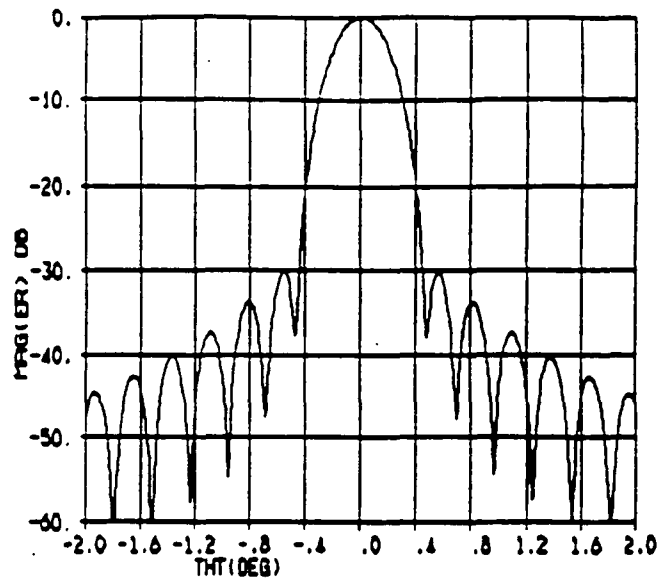
(b)

2-M PASS REFL SCANNED IN Y DIR., PHI=90., ET=-10, F=2

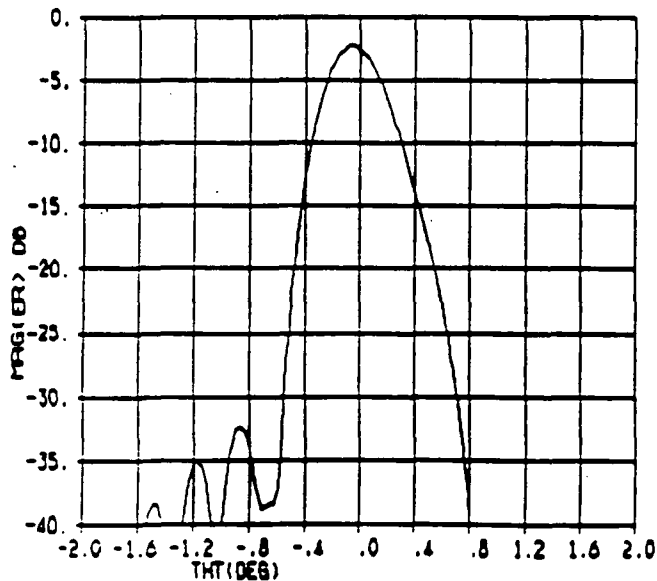


(c)

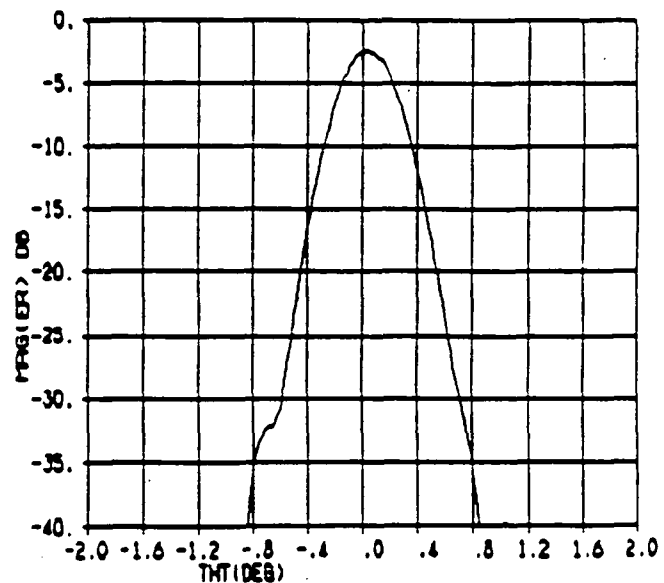
Figure 10. 2-meter antenna patterns for $F/D=1$, $ET=-10$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\text{PHI}=0^\circ$ and $\text{PHI}=90^\circ$ cuts.

2-M PASS REFLECTOR FEED ON FOCUS, $\text{PHI}=0^\circ$, $\text{ET}=-15$, $F=2$ 

(a)

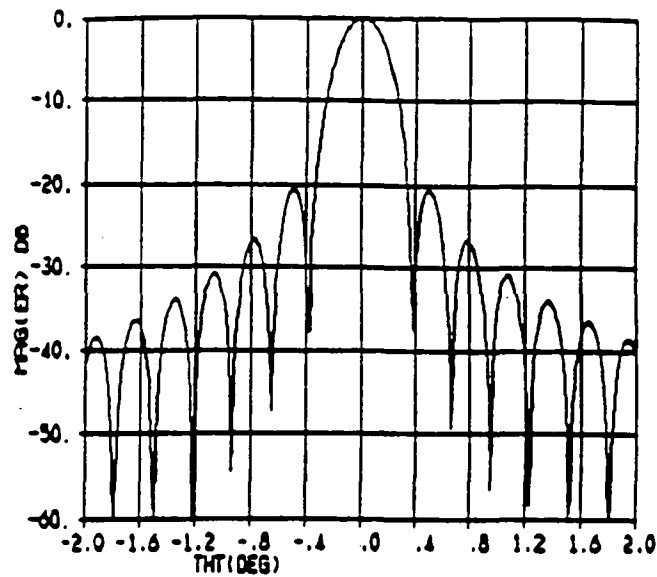
2-M PASS REFL SCANNED IN Y DIR., $\text{PHI}=0^\circ$, $\text{ET}=-15$, $F=2$ 

(b)

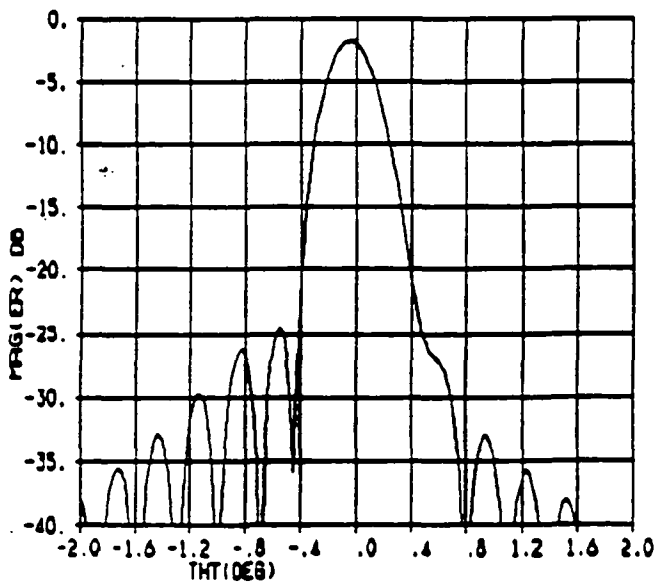
2-M PASS REFL SCANNED IN Y DIR., $\text{PHI}=90^\circ$, $\text{ET}=-15$, $F=2$ 

(c)

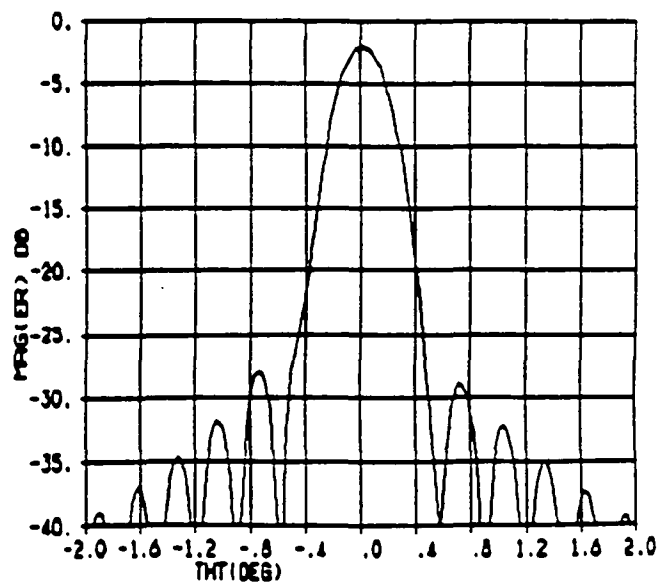
Figure 11. 2-meter antenna patterns for $F/D=1$, $\text{ET}=-15$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\text{PHI}=0^\circ$ and $\text{PHI}=90^\circ$ cuts.

2-M PASS REFLECTOR FEED ON FOCUS, $\Phi=0^\circ$, $ET=-5$, $F=25$ 

(a)

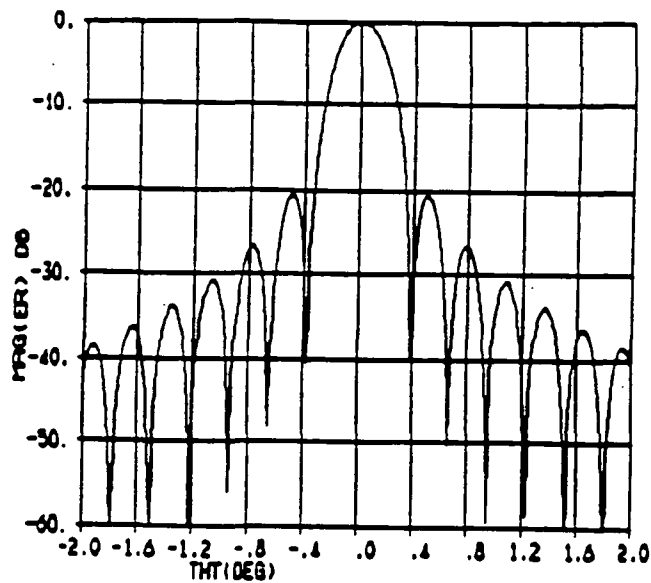
2-M PASS REFL SCANNED IN Y DIR., $\Phi=0^\circ$, $ET=-5$, $F=25$ 

(b)

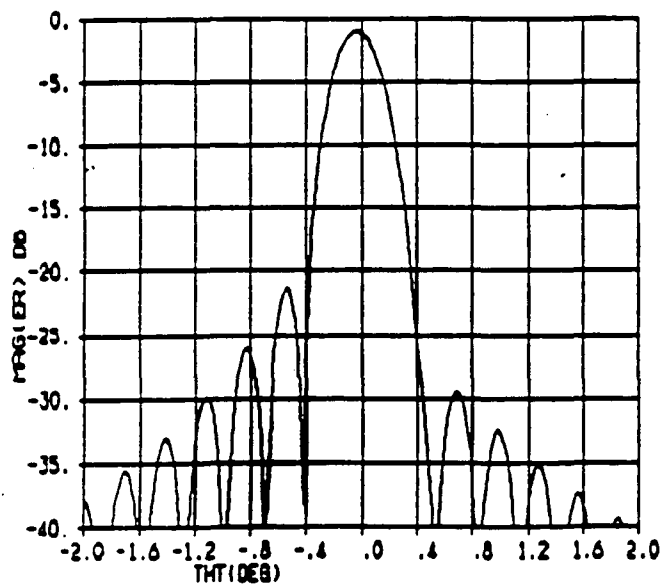
2-M PASS REFL SCANNED IN Y DIR., $\Phi=90^\circ$, $ET=-5$, $F=25$ 

(c)

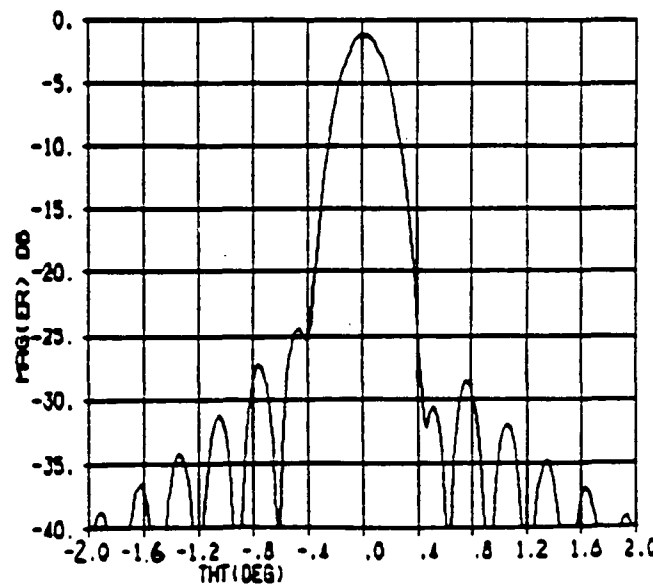
Figure 12. 2-meter antenna patterns for $F/D=1.25$, $ET=-5$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\Phi=0^\circ$ and $\Phi=90^\circ$ cuts.

2-M PASS REFLECTOR FEED ON FOCUS, $\Phi=0^\circ$, $ET=-5$, $F=3$ 

(a)

2-M PASS REFL. SCANNED IN Y DIR., $\Phi=0^\circ$, $ET=-5$, $F=3$ 

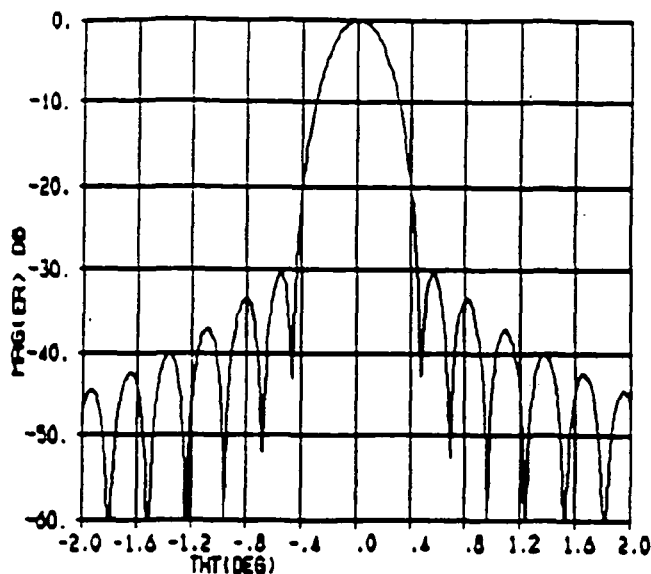
(b)

2-M PASS REFL. SCANNED IN Y DIR., $\Phi=90^\circ$, $ET=-5$, $F=3$ 

(c)

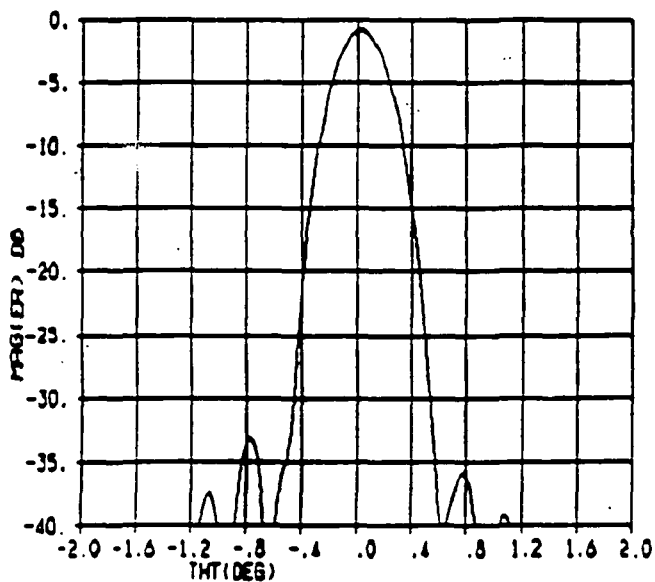
Figure 13. 2-meter antenna patterns for $F/D=1.5$, $ET=-5$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\Phi=0^\circ$ and $\Phi=90^\circ$ cuts.

2-M PASS REFLECTOR FEED ON FOCUS, PHI=0., ET=-15, F=3



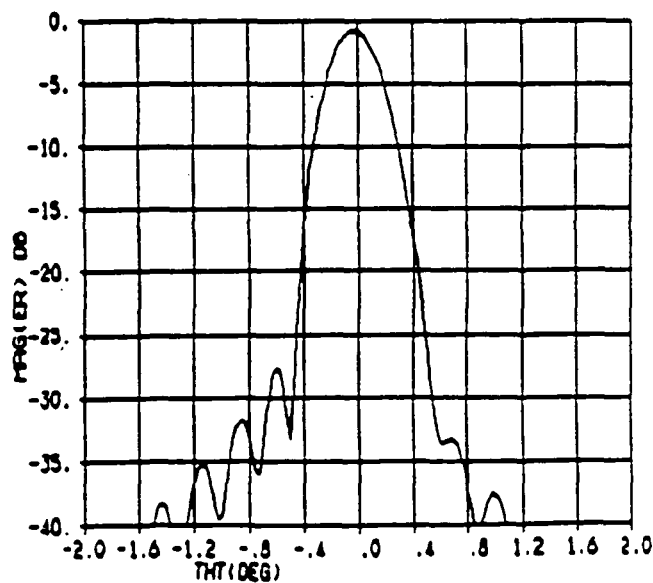
(a)

2-M PASS REFL. SCANNED IN Y DIR., PHI=90., ET=-15, F=3



(b)

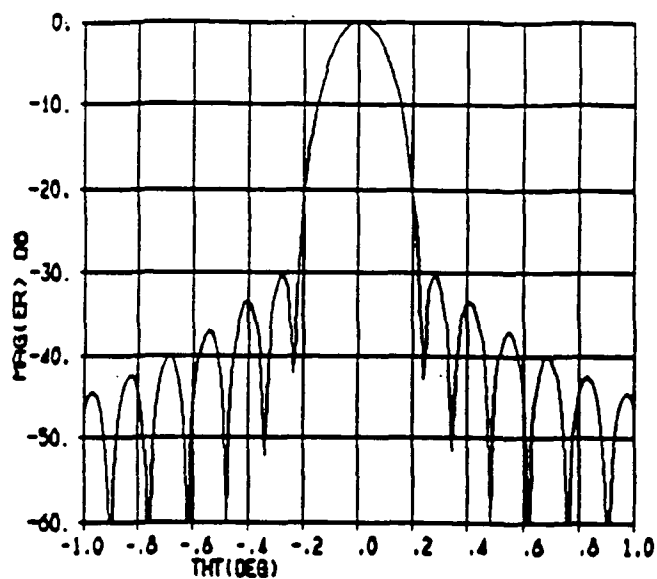
2-M PASS REFL. SCANNED IN Y DIR., PHI=0., ET=-15, F=3



(c)

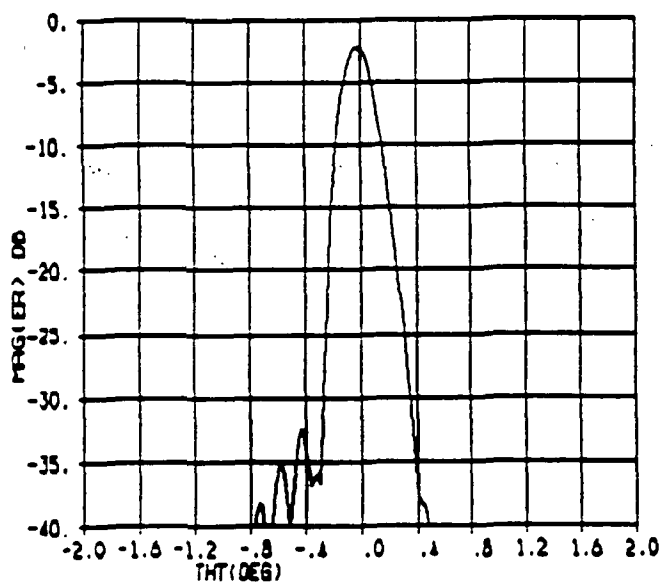
Figure 14. 2-meter antenna patterns for $F/D=1.5$, $ET=-15$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\text{PHI}=0^\circ$ and $\text{PHI}=90^\circ$ cuts.

4-H PASS REFLECTOR FEED ON FOCUS, PHI=0., ET=-15, F=6



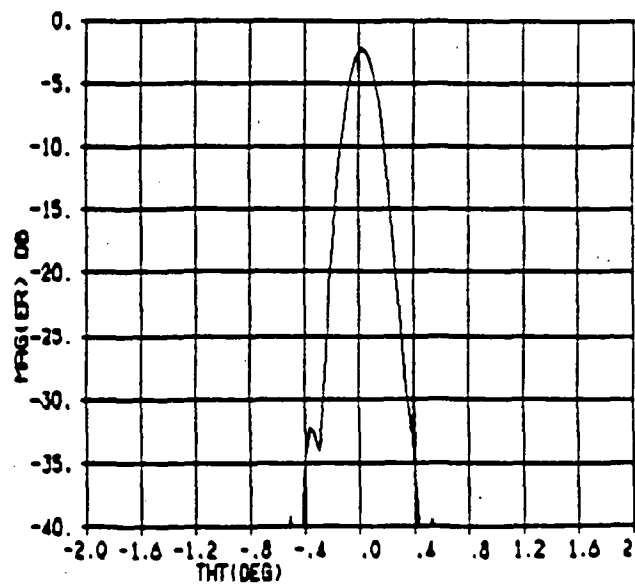
(a)

4-H PASS REFL SCANNED IN Y DIR., PHI=0., ET=-15, F=6



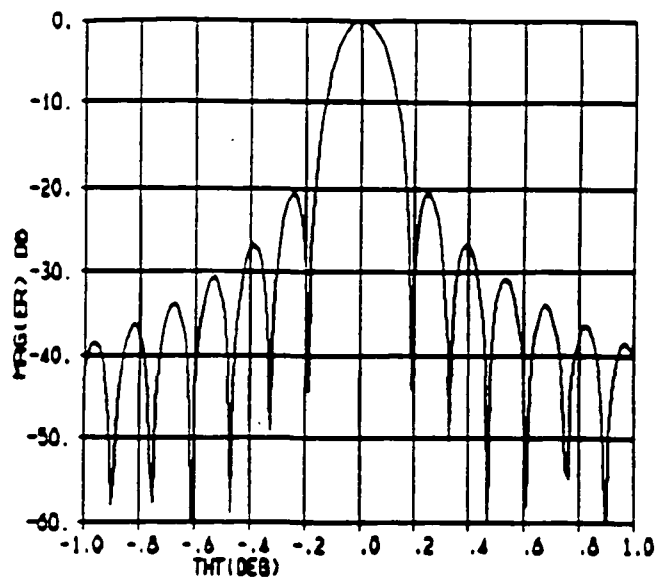
(b)

4-H PASS REFL SCANNED IN Y DIR., PHI=90., ET=-15, F=6

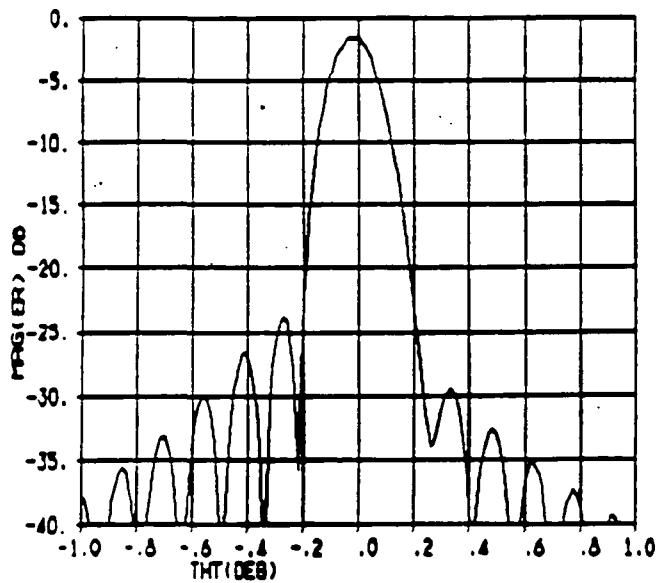


(c)

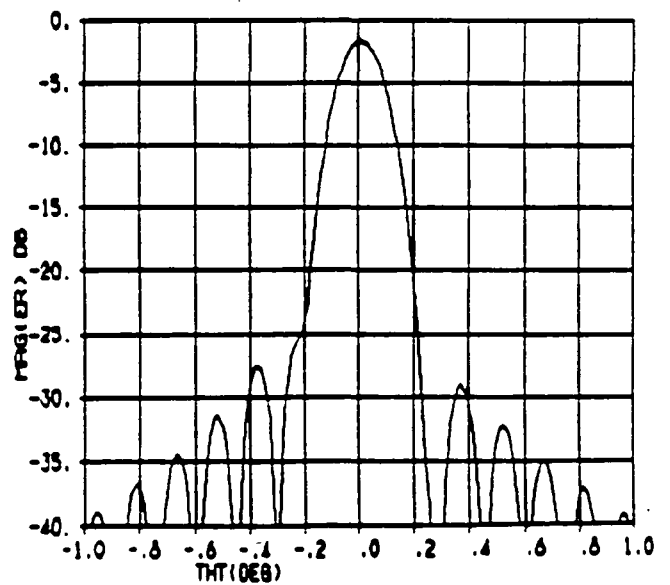
Figure 15. 4-meter antenna patterns for $F/D=1.5$, $ET=-15$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\phi=0^\circ$ and $\phi=90^\circ$ cuts.

4-M PASS REFLECTOR FEED ON FOCUS, $\Phi=0^\circ$, $ET=-5$, $F=8$ 

(a)

4-M PASS REFL SCANNED IN Y DIR., $\Phi=0^\circ$, $ET=-5$, $F=8$ 

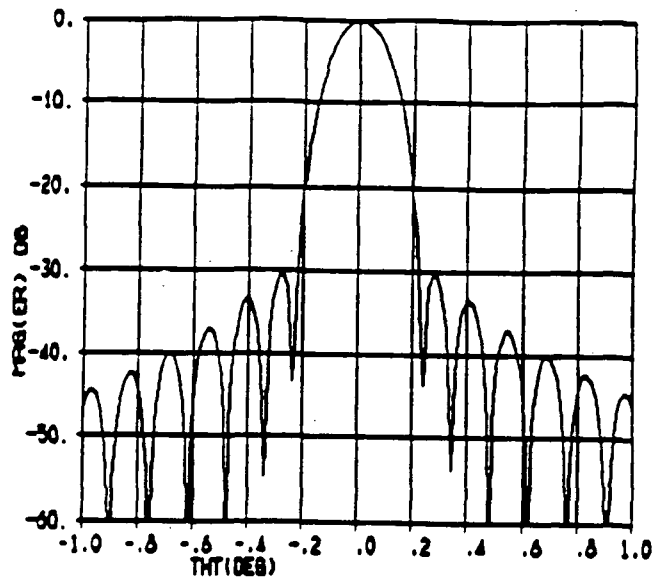
(b)

4-M PASS REFL SCANNED IN Y DIR., $\Phi=90^\circ$, $ET=-5$, $F=8$ 

(c)

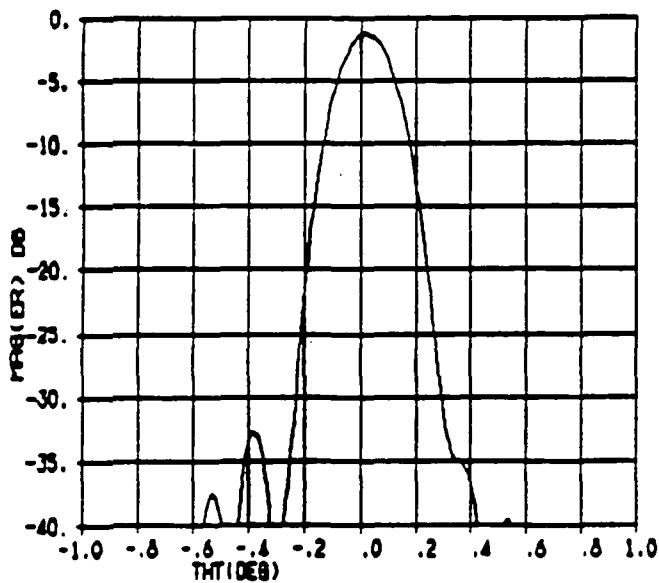
Figure 16. 4-meter antenna patterns for $F/D=2.0$, $ET=-5$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\Phi=0^\circ$ and $\Phi=90^\circ$ cuts.

4-M PASS REFLECTOR FEED ON FOCUS, PHI=0., ET=-15, F=8



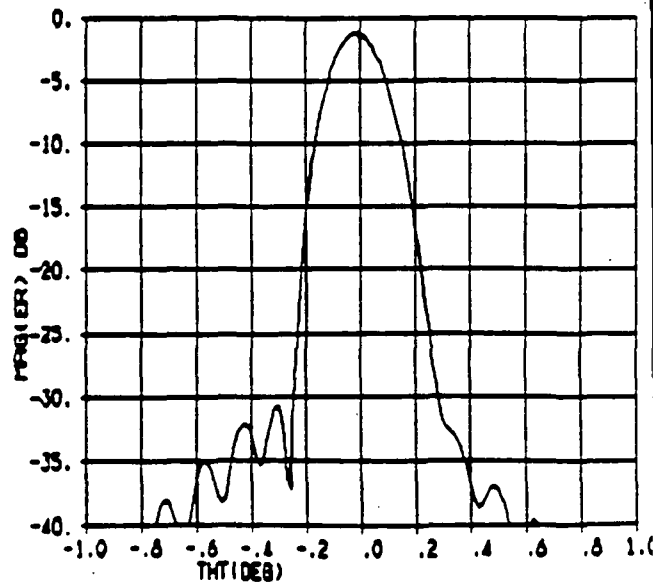
(a)

4-M PASS REFL SCANNED IN Y DIR., PHI=90., ET=-15, F=8



(b)

4-M PASS REFL SCANNED IN Y DIR., PHI=0., ET=-15, F=8



(c)

Figure 17. 4-meter antenna patterns for $F/D=2.0$, $ET=-15$; (a) Feed on focus; (b) and (c) Feed scanned in the Y direction, $\text{PHI}=0^\circ$ and $\text{PHI}=90^\circ$ cuts.

TABLE 1. TILT ANGLE OF VERTICAL POLARIZATION AT SELECTED CONUS LOCATIONS				
LENGTH UNIT: kilometer, ANGLE UNIT: degree				
POSITIVE AZIMUTH: ccw from south, POSITIVE ELEVATION: from ground up				
EARTH RADIUS:	6378			
SATELLITE POSITION:	ALTITUDE	LONGITUDE	LATITUDE	
	35838	-95.00	0.00	
ANTENNA BORESIGHT POSITION		-95.00	36.00	
	GROUND TERMINAL POSITION		POLARIZATION	
SITE	LONGITUDE		LATITUDE	TILT ANGLE
ARIZONA	-111.00		31.30	24.27
CALIFORNIA, CAPE	-120.50		34.50	31.89
CALIFORNIA, PASADENA	-118.14		34.15	29.93
CALIFORNIA, SOUTHWESTERN POINT	-117.00		32.50	30.30
CALIFORNIA, WESTERN MOST POINT	-124.50		40.50	29.79
FLORIDA TIP	-80.50		25.00	-28.12
KANSAS, KANSAS CITY	-94.70		38.90	-0.37
LOUISIANA	-90.00		29.00	-8.90
MAINE, NORTHEAST	-68.00		47.20	-22.65
MASSACHUSETTS, CAPE	-70.00		42.00	-24.99
MINNESOTA, NORTHERN BUMP	-95.00		49.40	0.00
MONTANA, MID-NORTHERN BOUNDARY	-110.00		49.00	12.60
NORTH CAROLINA	-75.50		36.00	-24.54
PUERTO RICO, SAN JUAN	-66.00		18.00	-55.94
TEXAS, WESTERN COAST	-97.40		25.80	4.93
TEXAS, WESTERN END	-103.20		29.00	14.37
WASHINGTON D.C.	-77.03		38.89	-20.81
WASHINGTON, NORTHWEST	-124.70		48.40	23.59
ALASKA, ANCHORAGE	-150.00		61.50	23.80
ALASKA, KETCHIKAN	-130.00		55.00	21.73
ALASKA, KODIAK	-152.00		57.50	27.91
ALASKA, LITTLE ISLAND	-180.00		52.00	37.63
ALASKA, NOME	-165.00		64.50	23.96
ALASKA, PRUDHOE	-148.00		71.00	15.26
ALASKA, PT BARROW	-157.00		73.00	14.99
HAWAII, HONOLULU	-157.80		21.40	65.84
CANADA, EASTERN MOST POINT	-53.00		47.00	-31.75
CANADA, WESTERN MOST POINT	-141.00		69.60	14.86

Table 2: 2-meter Antenna On- and Off-Axis Gain and Efficiency as a Function of F/D and ET.

F/D	ET	On-Axis Gain, dB (Efficiency, %)	Off-Axis Gain, dB (Efficiency, %)
1.0	-10	54.9 (78.3)	51.8 (38.3)
1.0	-15	55.0 (80.0)	52.5 (45.0)
1.25	-5	54.3 (68.2)	52.2 (42.0)
1.5	-5	54.3 (68.2)	53.0 (50.5)
1.5	-15	54.9 (78.3)	53.9 (62.2)

Table 3. 4-meter Antenna on- and Off-Axis Gain and Efficiency as a Function of F/D and ET.

F/D	ET	On-axis Gain, dB (Efficiency, %)	Off-Axis Gain, dB (Efficiency, dB)
1.5	-15	60.9 (77.9)	58.5 (44.6)
2.0	-5	60.3 (67.9)	58.5 (44.8)
2.0	-15	60.9 (77.9)	59.6 (57.8)

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Appendix I. Polarization Options for the PASS System

(P. Cramer)

An open issue for the PASS program is the choice of polarization, linear vs. circular. Linear polarization is the simplest to implement both on the satellite and in the ground terminal and therefore would be the preferred polarization type if it has no performance limitations. The primary limitation would be if the angle (polarization angle) between the effective polarization vectors of the satellite and ground user terminal antennas were of a sufficient magnitude such that the polarization loss exceeded an acceptable level. If the polarization loss is unacceptable, then circular polarization would be required since circular polarization does not suffer a loss associated with a polarization angle.

To resolve this issue, the polarization angle for linear polarization was calculated for typical satellite/ground user terminal geometries. The following definition is used to define the polarization angle. See Figure 1. Two planes, both containing the line of sight between the satellite antenna and the ground user antenna, will be defined with the angle between the two planes being the polarization angle. The first plane will be defined by the line of sight and the polarization vector of the ground user antenna (such as the local vertical for vertical polarization). The user terminal effective polarization vector is in this plane and at a right angle to the line of sight. The second plane will be defined by the line of sight vector and the satellite antenna polarization vector (such as vertical polarization). Again the satellite antenna effective polarization vector is in the second plane and at a right angle to the line of sight. The angle then between the effective polarization vectors and hence the two planes defines the polarization angle. This definition was selected to eliminate the possibility of including pattern directivity effects in the computation of the polarization angle. The polarization power loss would then be equal to the square of the cosine of the polarization angle.

The assumptions were made that the satellite is in a geo-synchronous orbit midway across the continental US (95.0 W longitude) and has the antenna boresighted approximately at the middle of CONUS so that CONUS type pattern coverage could be provided. The polarization angle was then calculated for user ground terminals located around the periphery of the country as this should identify the worst cases. The polarization angles were computed for both vertical and horizontal polarization where the polarization of the user terminal antenna is defined to be either along or normal to the local vertical. Table 1 summarizes the geometry and in the last column, lists the polarization angles associated with each location. The worst cases are along the western and eastern coastlines with the angles getting larger towards the south. With angles ranging from 22 to 30 degrees, this represents polarization losses of from 0.7 to 1.3 dB. However since the ground user terminals must include hand held devices that can not be oriented accurately, the effect of orientation errors must be included in the polarization angle determination. No attempt was made to accurately define what the extent of the orientation errors would be in typical usage, however to get a feel for the effect of such errors, it was assumed that realistic errors would be between 25 to 30 degrees. 27 degrees was specifically selected since this represents a loss of 1.0 dB. Adding this orientation angular error in the worst case direction to the polarization angles in Table 1 gives polarization losses from 3.7 to 5.3 dB. If the orientation errors are any larger, the losses are going to increase rapidly since the cosine of an angle changes rapidly for angles larger than 50 degrees.

Tables 2 and 3 show cases where the satellite is located towards the western and eastern ends of the country to determine the effect of the satellite location on polarization angle. As can be seen the worst case polarization angles are approximately 45 degrees. Orientation errors would have to be held within 12 degrees if losses similar to the centrally located satellite case are to be obtained. However, while the polarization error increased along one coastline, it improved along the opposite coastline. If the satellite antenna is adjusted about its boresight axis, it is possible to balance the polarization angles between each coast and the losses should be comparable to the case for the

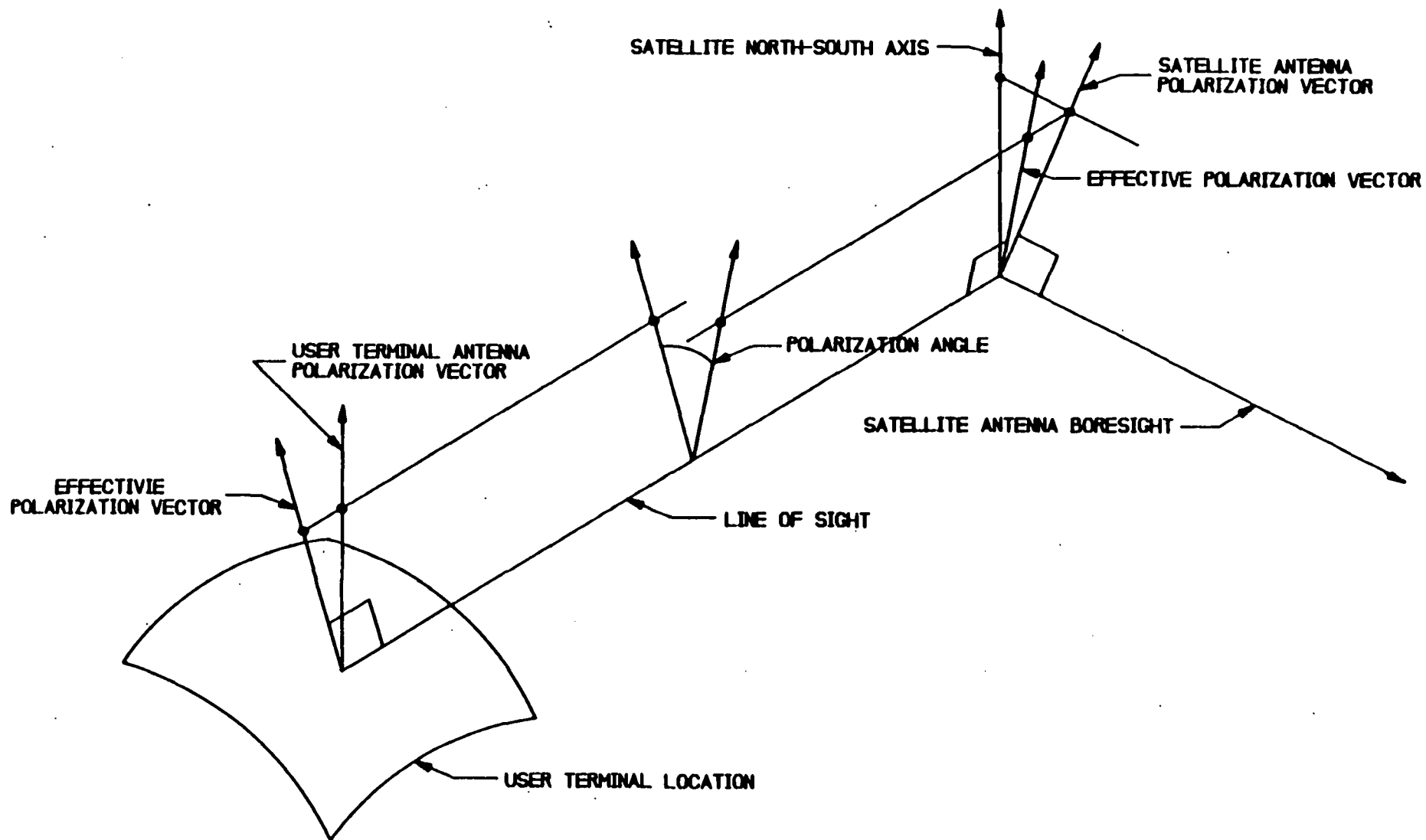
centrally located satellite. However, it might not always be possible to adjust the satellite antenna to minimize the polarization angle if redundant or multiple satellites are used in different locations and there is a need to be able to move the satellites to any of these assigned orbit location.

The possibility exists that the polarization orientation of each feed element in the satellite antenna feed array could be adjusted to match the user terminal polarization at the beam direction associated with that feed element. This would eliminate the satellite to user local vertical polarization loss. However, it still does not eliminate the user terminal orientation errors as the 27 degree error equates to a 1.0 dB loss. This solution still has the limitation as to the range in satellite locations that could be supported since it is not feasible to custom design the satellite antenna for each satellite location.

If circular polarization is used, there could be as much as 0.4 dB in increased losses for the user terminal. For a typical patch antenna design, an additional power splitter would be required to generate circular polarization and the additional microstrip circuitry could cut down on the efficiency of the required dual frequency design. The satellite antenna system is to have separate antennas for each frequency and since costs are not as critical for a satellite antenna, it is conceivable that a lower loss solution should be attainable to produce circular polarization, with a loss lower than 0.2 dB.

It is my recommendation that circular polarization be used for the PASS program for the following reasons: Since handheld terminals must be supported by the PASS program, it is not reasonable to expect the average user to be able to control the orientation of their terminal any better than 27 degrees. Assuming that the satellite to user terminal local vertical optimization is used then, polarization losses on the order of 1.0 dB or more can still be expected assuming a terminal orientation error of 27 or more degrees. Even with the circular polarization implementation losses on the order of 0.5 dB, 0.5 dB or more improvement could be obtained with circular polarization. Secondly, if it is not feasible for what ever reason to optimize the satellite antenna

design, then losses as high as 5.0 dB would result, considerably higher than the circular polarization implementation losses. Thirdly it does not seem practical to give up the mission flexibility of being able to locate a given satellite or satellite design in more than one orbit location simply to utilize linear polarization. Commercial satellites in the past have had to live with the fact that in many cases it was not known what their specific orbit location assignments would be until close to launch time. There is no reason to expect that this problem will change in the future. The main argument used in favor of linear polarization is cost and possibly weight. However, with the continual development of integrated and etched antenna circuits and technology, and considering the time frame in which the PASS system would be widely used, there should be very little difference in cost and weight between the two polarization types. The differences in cost will show up primarily as development costs and should be able to be amortized over a large user base and it is part of the technology development activity to make this happen. And lastly, circular polarization leaves open the possibility to take advantage of new antenna concepts or system requirements that might be developed in the future that would not be compatible with linear polarization.



POLARIZATION ANGLE DEFINITION

FIGURE 1

Table 1

SATELLITE/GROUND STATION GEOMETRY

DATE: 11-02-88. TIME: 03:05:13.65 PM

SATELLITE DESCRIPTION:

LATITUDE = .000 DEG ALTITUDE = 35838.052 KM
 LONGITUDE = -95.000 DEG EARTH RADIUS = 6378.160 KM

ANTENNA BORESITE LOCATION:

LATITUDE = 36.000 DEG ALTITUDE = .000 KM ELEVATION = 3.777 DEG
 LONGITUDE = -95.000 DEG AZIMUTH = .000 DEG

GROUND TERMINAL LOCATION	IN EARTH COORD.		RANGE (KM)	IN ANTENNA COORD		SATELLITE LOCATION ELEV/AZ	POLARIZATION ANGLE VERT/HORI
SITE	LAT./LONG.	ALT.		NORMAL/TILDE POLAR AZIMUTH			
Seattle, Wash	47.597 -122.330	.000	38733.406	3.165 88.785	67.422 87.077	29.227 145.013	22.630 22.568
San Francisco, Calif	37.775 -122.417	.000	38013.671	3.504 89.867	87.822 86.499	37.692 139.742	30.544 30.536
Los Angeles, Calif	34.058 -118.250	.000	37589.490	3.197 90.315	95.663 86.819	43.252 142.506	30.114 30.131
San Diego, Calif	32.713 -117.153	.000	37459.718	3.135 90.489	98.975 86.903	45.069 143.007	30.247 30.273
El Paso, Tex	31.755 -106.480	.000	37069.400	1.766 90.579	109.142 88.331	50.981 158.899	17.732 17.750
Houston, Tex	29.763 -95.362	.000	36815.947	.845 90.843	176.307 89.946	55.301 179.271	.630 .631
Miami, Florida	25.775 -80.190	.000	36797.485	2.708 91.450	237.619 92.287	55.635 211.301	-27.750 -27.808
Norfolk, Va	36.845 -76.287	.000	37612.656	2.496 89.935	271.488 92.495	42.934 209.461	-23.054 -23.051
Van Buren, Maine	47.158 -67.942	.000	38688.306	3.150 88.826	291.881 92.924	29.730 214.863	-22.755 -22.695
Detroit, Mich	42.333 -83.050	.000	37860.493	1.652 89.261	296.580 91.478	39.640 197.447	-12.740 -12.721
Duluth, Minn	46.783 -92.113	.000	38139.171	1.267 88.777	344.883 90.331	36.141 182.959	-2.696 -2.689
Billings, Mont	45.780 -108.505	.000	38179.834	1.909 88.899	54.762 88.441	35.645 161.473	12.740 12.710
Kansas City, Mo	39.100 -94.578	.000	37483.084	.388 89.616	351.736 90.056	44.737 180.669	-5.517 -5.516

Table 2

SATELLITE/GROUND STATION GEOMETRY

DATE: 11-02-88. TIME: 04:19:22.30 PM

SATELLITE DESCRIPTION:

LATITUDE = .000 DEG ALTITUDE = 35838.052 KM
 LONGITUDE = -110.000 DEG EARTH RADIUS = 6378.160 KM

ANTENNA BORESITE LOCATION:

LATITUDE = 36.000 DEG ALTITUDE = .000 KM ELEVATION = 5.746 DEG
 LONGITUDE = -95.000 DEG AZIMUTH = -2.054 DEG

GROUND TERMINAL LOCATION IN EARTH COORD.

SITE	LAT./LONG.		ALT.	RANGE (KM)	IN ANTENNA COORD		SATELLITE LOCATION ELEV/AZ	POLARIZATIO ANGLE VERT/HORIZ
					NORMAL/TILDE POLAR	AZIMUTH		
Seattle, Wash	47.597	-122.330	.000	38316.020	3.661	68.774	34.013	10.776
					88.675	86.587	163.510	10.697
San Diego, Calif	32.713	-117.153	.000	37058.179	3.105	97.422	51.162	10.710
					90.401	86.921	166.927	10.732
Miami, Florida	25.775	-80.190	.000	37444.799	2.764	237.271	45.282	-45.762
					91.494	92.325	232.803	-45.823
Van Buren, Maine	47.158	-67.942	.000	39382.857	2.442	296.202	22.286	-31.882
					88.922	92.191	230.900	-31.842

Table 3

SATELLITE/GROUND STATION GEOMETRY

DATE: 11-02-88. TIME: 04:28:16.40 PM

SATELLITE DESCRIPTION:

LATITUDE = .000 DEG ALTITUDE = 35838.052 KM
 LONGITUDE = -80.000 DEG EARTH RADIUS = 6378.160 KM

ANTENNA BORESITE LOCATION:

LATITUDE = 36.000 DEG ALTITUDE = .000 KM ELEVATION = 5.746 DEG
 LONGITUDE = -95.000 DEG AZIMUTH = 2.054 DEG

GROUND TERMINAL LOCATION IN EARTH COORD.			RANGE (KM)	IN ANTENNA COORD		SATELLITE LOCATION ELEV/AZ	POLARIZATION ANGLE VERT/HORIZ
SITE	LAT./LONG.	ALT.		NORMAL/TILDE POLAR	AZIMUTH		
Seattle. Wash	47.597	.000	39426.153	2.445	62.758	21.841	31.625
	-122.330			88.881	87.826		129.030
San Diego. Calif	32.713	.000	38232.857	2.874	101.377	35.005	43.174
	-117.153			90.567	87.183		125.497
Miami. Florida	25.775	.000	36577.959	2.454	235.367	59.876	.597
	-80.190			91.394	92.019		179.563
Van Buren. Maine	47.158	.000	38272.498	3.630	290.705	34.531	-10.705
	-67.942			88.717	93.396		196.243

APPENDIX II
Overlapping vs. Non-overlapping Feed Apertures for
the PASS Satellite Antenna Concept

P. Cramer

One of the issues that needs to be resolved for the PASS Program satellite antenna design is whether or not overlapping apertures are required. The purpose of this memorandum is to address some of the issues so that a decision can be made.

A single non-overlapping feed aperture is the simplest design since a beam forming network is not required. This is reflected in a lower cost design with lower losses. However, for a design based on a crossover level of 3 dB between adjacent beams, the non-overlapping aperture has a higher illumination efficiency because the feed aperture size available causes the main reflector to be over-illuminated. The negative side of over-illuminating is a low spillover efficiency and a low crossover level between adjacent beams because of narrow beamwidths.

Overlapping aperture designs are not limited by the space available between the feed centers in the reflector focal plane. If the feed elements for one beam are allowed to overlap the feed elements for an adjacent beam, then the feed can be made as large as necessary to optimize the reflector illumination. Typically, the spillover efficiency will improve, but the illumination efficiency will drop as a result of larger edge tapers. The larger edge tapers however, produce lower side lobe levels and therefore the overlapping design is best for frequency reuse applications where high isolation is needed. In addition, the broader beamwidths associated with the lower illumination efficiencies produce higher crossover level between adjacent beams. Overlapping aperture designs require elaborate beam forming networks that are costly and introduce dissipative losses.

For the PASS program, in order to make the proper choice, the constraints must be identified. Frequency reuse is not a requirement. Therefore the high isolation of the overlapping design is not needed. However performance is a critical factor. The PASS concept design indicates that the basic personal terminal must have a gain of 22.8 dB at 30 GHz and provide an output power of 0.3 watt. However it turns out that these performance requirements are not compatible with the requirement that the terminal design not violate RF radiation safety standards [1]. From Figure 7 of reference [1], it turns out that a gain of about 29 dB and a power of only 0.072 watts are needed to reduce the radiated power density to a safe level and still provide the required EIRP. To market an user terminal with 29 dB gain would be prohibitively expensive. In any design, the cost of a ground terminal must be kept low to attract users and to achieve this, system complexity should be shifted to the satellite. Even at an increase cost to the satellite, the overall program costs normally would be lower. To reduce the user terminal gain, the user terminal EIRP must be reduced and the satellite performance

increased accordingly. To satisfy the higher satellite performance requirements, cost of the satellite antenna system is no longer the prime driver. Increasing the satellite antenna size to increase the gain to noise temperature ratio to compensate for the loss of EIRP from the user terminal is not attractive from a cost standpoint until the antenna efficiency has been maximized. Thus the choice between an overlapping feed design and a non-overlapping design should be made based on performance and to a much lesser degree on costs.

To compare the two feed concepts, the antenna configuration presented in the trade-off section of the "Second-Generation Mobile Satellite System" study [2] was used. From part two, section 2.7, the single element cluster with four patches per element is used as a typical example of a non-overlapping feed. The six element cluster with two patches per element is used as a good example of an overlapping feed. In all cases, the same patch size and spacings were used. From the study report, the single element cluster had a peak gain (or efficiency) 0.18 dB higher than the six element cluster. To gain more insight into the relative merits of the two configurations, the patterns of the two configurations were analyzed using the pattern efficiency program. The results are summarized in Table 1 and are identified as the "nominal" cases in the table. Equal excitations were used for all element and patches. The difference in efficiency for the two configurations with the base line F/D of 1.08 is 0.09 dB in favor of the single element cluster. The efficiency program is based on symmetrical reflector designs, while the cases analyzed in the system study are for offset designs. Since the two approaches give differences in efficiencies which are within 0.09 dB of each other (0.18 - 0.09), the efficiency program is still useful in performing trade-offs between various offset designs and provides additional insights since efficiency contributors such as spillover, illumination, phase, cross-polarization, etc are individually identified. Due to the broader secondary pattern of the six element cluster, the six element cluster had an adjacent beam cross-over level of approximately 1.1 dB higher than for the single element cluster. This gives the six element cluster a net improvement of 1.0 dB over the single element cluster.

Table 1 also shows the F/D at which each configuration has the highest efficiency. These cases are identified as the "maximum" cases in Table 1. The results imply that if no changes are made in the feed design and reflector diameter, the antenna would have it's best performance if it had the F/D indicated. The single element cluster would require a F/D of 0.81 which is not attractive since it would have a degraded outer beam performance and a smaller area available for the feed in the focal plane. However, the six element cluster's best F/D is 1.38. If the feed separation that is used for the F/D of 1.08 design is also used for a F/D of 1.38 case, then the adjacent beams would move closer together by about 22 percent. Using equation 2-2 from the study report, the crossover level between adjacent beams for the six element cluster with a F/D of 1.38 would be 1.14 dB higher than for the single element cluster with a F/D of 1.08. This comparison is reasonable

since the illumination efficiency of the two cases are close, implying similarly shaped secondary patterns. Adding the gain improvement associated with the higher efficiency of the six element cluster at a F/D of 1.38 with the efficiency of the single element cluster at a F/D of 1.08 (0.42 dB) gives an overall improvement for the six element cluster of about 1.56 dB. More accurate comparisons should be made by calculating the secondary pattern for the larger F/D case, this type of calculation being beyond the scope of this review. However the size of the improvements (approximately 1.0 dB for F/D of 1.08 and 1.6 dB for F/D of 1.38) indicate that the six element cluster represents a worth while improvement over the single element cluster.

The example above indicates that an overlapping aperture design can provide a significant improvement over a non-overlapping design if it is assumed that there are no network losses associated with the overlapping design. Otherwise a considerable part of the improvement could be lost to dissipative losses, perhaps approaching a wash between the two concepts. If this is the case then a non-overlapping design would be preferable because of simplicity and cost. To make the overlapping design viable, then a method to reduce or eliminate the network losses is required. It is suggested that a low noise preamplifier and a power amplifier stage with diplexer could be placed between the feed elements and the beam forming network to eliminate this loss.

The recommendation for the PASS program then, is to use overlapping feed apertures to obtain higher antenna performance and to locate preamplifiers and power amplifiers behind the feed elements to eliminate the associated network losses. This also opens the possibility of exploring the implementation of the beam forming network at IF frequencies to see if improved performance, packaging size and weight might be found. The enabling technology that would need to be developed would include: 1) low loss linear power amplifier, pre-amplifier and diplexer modules, 2) fabrication methods to make them cheaply and compactly, 3) efficient methods to mount and interconnect each module, and 4) methods to integrate the modules with the feed elements.

References:

- [1] Memorandum from P. Cramer to K. Woo, "R.F. Radiation Concerns Associated With The PASS User Terminals", December 30, 1988
- [2] M.K. Sue, Y.H. Park, "Second-Generation Mobile Satellite System", JPL Publication 85-58, June 1, 1985, Part Two, Pages 2-51 to 2-74

Table 1
ANTENNA EFFICIENCIES

ELEMENTS PER CLUSTER	PATCHES PER ELEMENT	CASE	EDGE ANGLE DEG	F/D	EFFICIENCIES		
					TOTAL	SPILL	ILLUM
1	4	NOMINAL	25.950	1.085	.7059	.7329	.9633
6	2	NOMINAL	25.950	1.085	.6908	.9248	.7488
3	4	NOMINAL	25.950	1.085	.6221	.8775	.7230
1	4	MAXIMUM	34.492	0.805	.8025	.9041	.8877
6	2	MAXIMUM	20.582	1.377	.7782	.8696	.8960
3	4	MAXIMUM	19.924	1.423	.7237	.8119	.8956

Appendix III. Some Antenna Design Options for 20/30 GHz PASS system

(Y. Rahmat-Samii)

The main objective of this work is to present some new design options for the PASS high gain spacecraft antenna configurations. Usually, most of the studies are focussed on the application of offset parabolic and Cassegrain reflector antennas with large focal lengths (large F/D ratios). See, e.g., Section 6.5, and also Reference [1] for a detailed investigation. One of the key parameters in achieving the design requirements is to generate beams with many beamwidths scan performance. As discussed in section 6, for a complete CONUS coverage the antenna must generate beams with scan capabilities of up to 3.5 degrees off boresight. For example, for a 4.0 meter antenna operating at 30 GHz, over ± 20 BW scan angle is required.

The concepts studied here involve the use of a small movable array to produce an optimized beam. Both symmetric parabolic and spherical reflector antennas are considered. Attention is given to the nature of the excitation coefficients for both on-axis beams and off-axis beams in the 3.5° scan direction.

The geometry of a symmetric parabolic antenna is shown in Figure 1. For this configuration, the antenna performance, using a single feed element as well as a small feed array is studied. Results are summarized in Table 1. Note that the off-axis beams are generated by moving either the single element feed or the small array feed to a proper location in the focal plane of the reflector. Both 7-element and 19-element feed arrays are considered. In order to improve the off-axis performance, the excitation coefficients of the array elements were optimized using the technique presented in [2].

A similar investigation has been performed using a spherical reflector antenna. The geometry of the reflector is shown in Figure 2. It should be noticed that the effective focal point for this reflector is approximately midway between the center of the sphere and the apex point of the reflector. Results of the computer simulation are shown in Table 1. It must be noted that due to the spherical aberration, the single feed configuration does not lend itself to satisfactory results. However, as shown in Table 1, the 19-element array feed does improve the performance considerably. An advantage of using the aberration-corrected spherical reflector is that the same array can be used for the scanned beams. This is due to the rotational symmetry of the spherical reflector. Note that the feed array is positioned in a location with 3.5° tilt angle with respect to the original axis.

Studies need to be conducted for the use of large arrays off the focal plane of the offset parabolic, hyperbolic or other types of reflectors. The purpose of such investigations will be to demonstrate the potential applicability of simple single-reflector electronic beam steering.

The above options should provide new design considerations for the reflector array configurations. More detailed evaluations will be needed to fully characterize the overall advantages of these concepts.

REFERENCES

- [1] Final Report 30/20 GHz Lewis Antenna Support, JPL ACC. No. 343-10104-0-3360, February 1981.
- [2] Y. Rahmat-Samii, "Improved Reflector Antenna Performance Using Optimized Feed Arrays," Proceedings of 1989 URSI International Symposium, Stockholm, Sweden, August 1989, pp. 559-561.

1 - ELEMENT

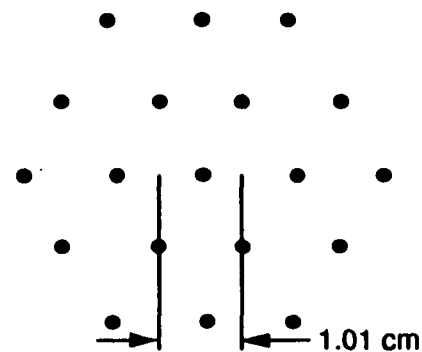
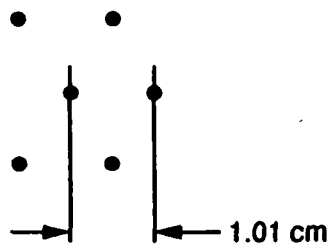
7 - ELEMENT

19 - ELEMENT

$q = 13.80$

$q = 2.25$

$q = 2.25$



FEED ARRAY WITH ELEMENT PATTERN $\cos^q(\theta)$

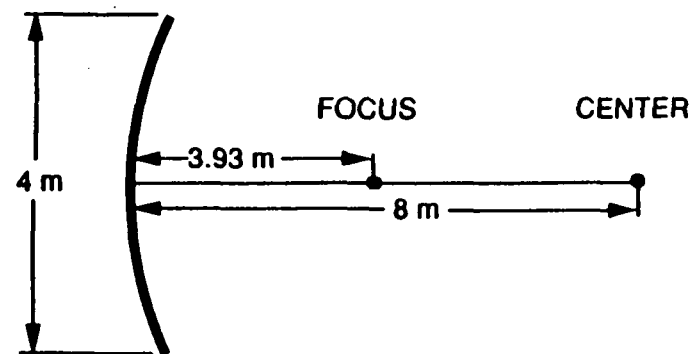
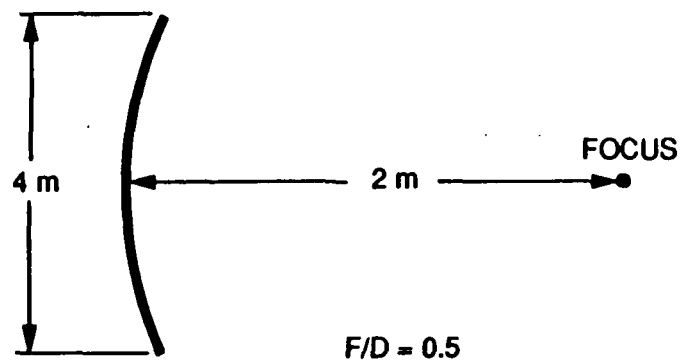


Figure 1. Geometry of a Symmetric Parabolic Reflector

Figure 2. Geometry of a Symmetric Spherical Reflector

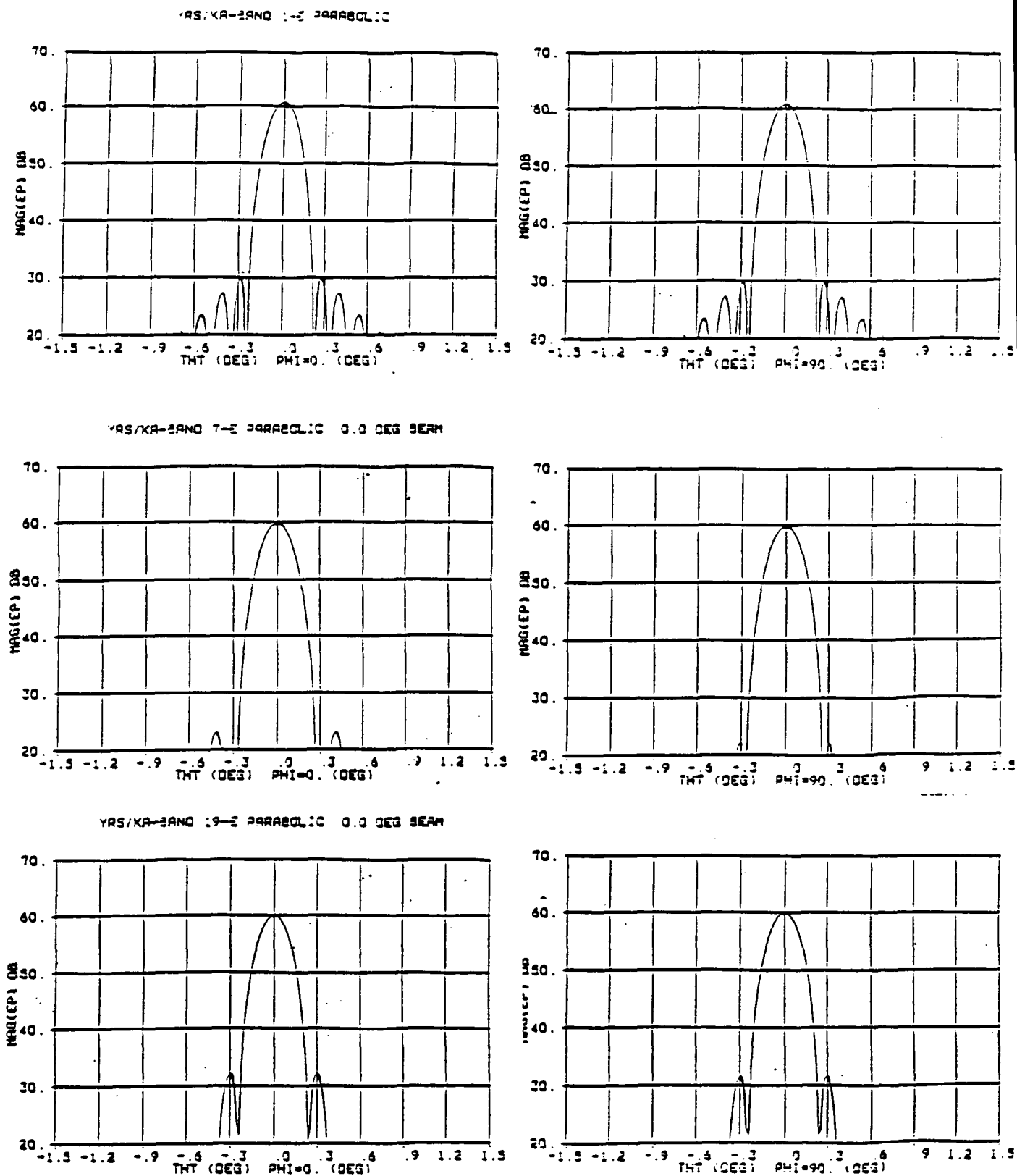
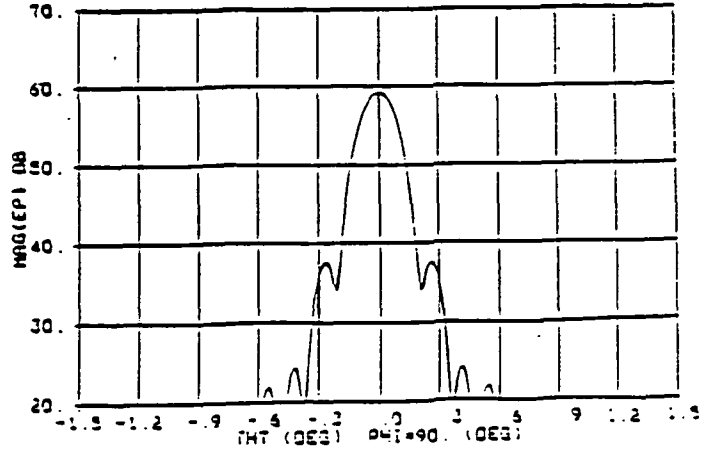
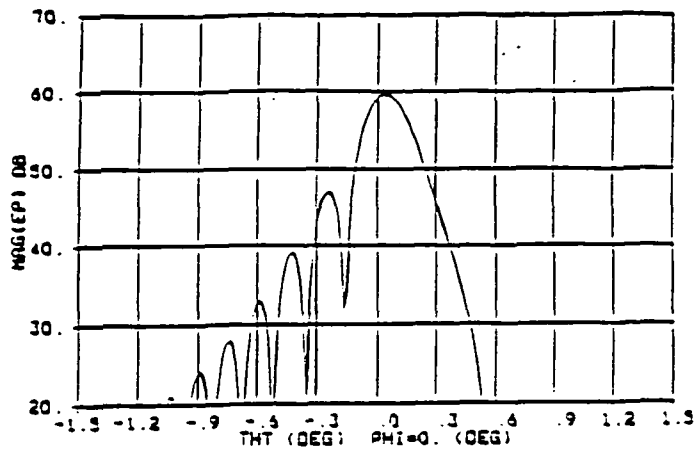
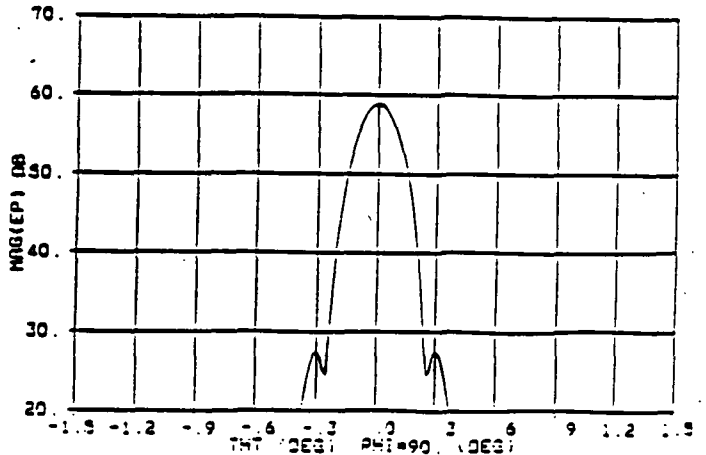
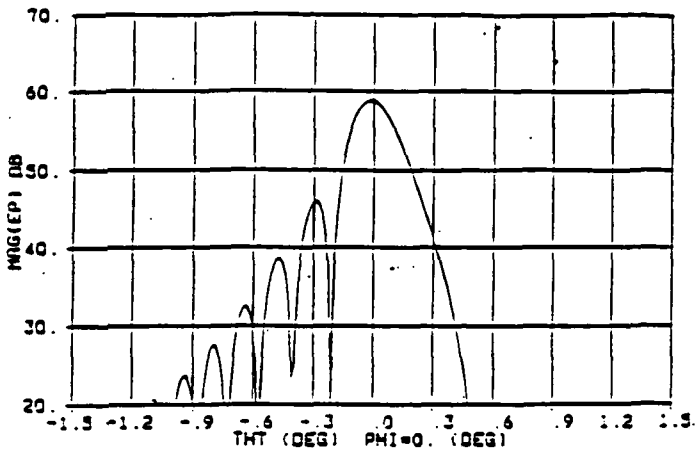


Figure 3. Calculated Patterns of symmetric parabolic reflector with 1, 7, and 19 element feed arrays. Scan angle: 0°

YRS/KR-2880 1-2 PARABOLIC 3.5 DEG BEAM



YRS/KR-2880 7-2 PARABOLIC 3.5 DEG BEAM



YRS/KR-2880 19-2 PARABOLIC 3.5 DEG BEAM

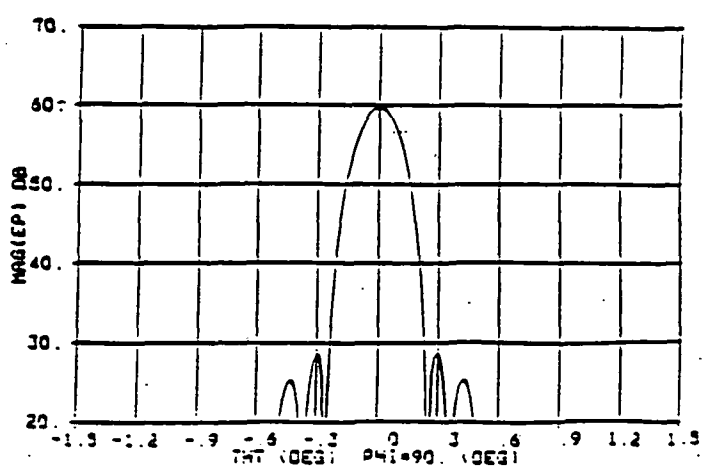
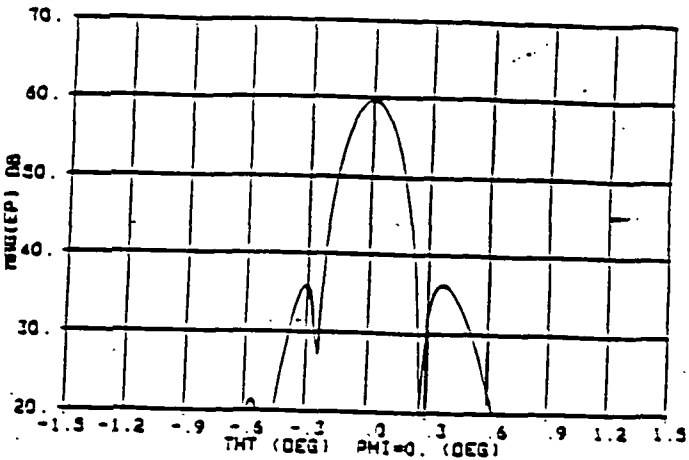


Figure 4. Calculated Patterns of symmetric parabolic reflector with 1, 7, and 19 element feed arrays. Scan Angle: 3.5°

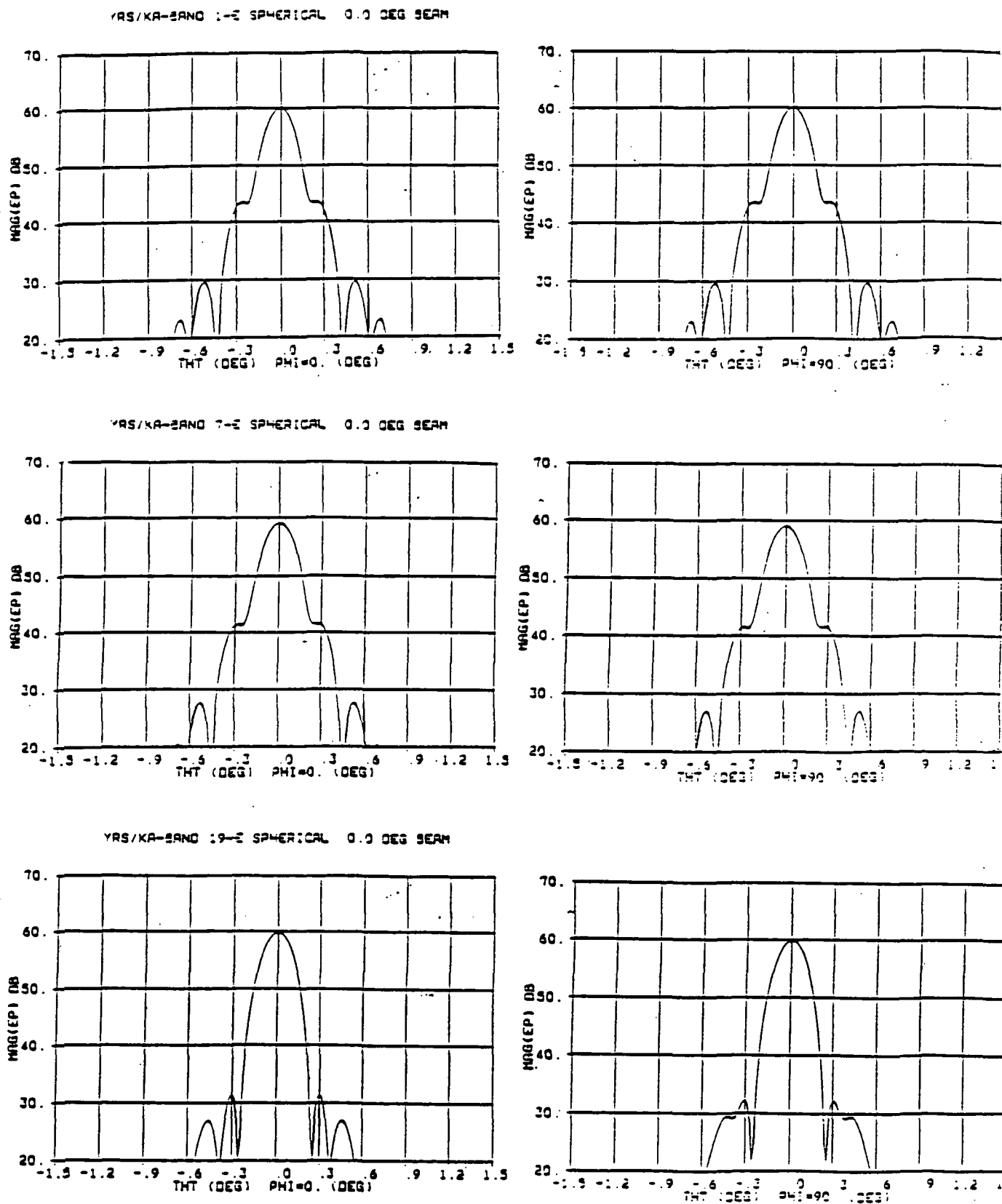
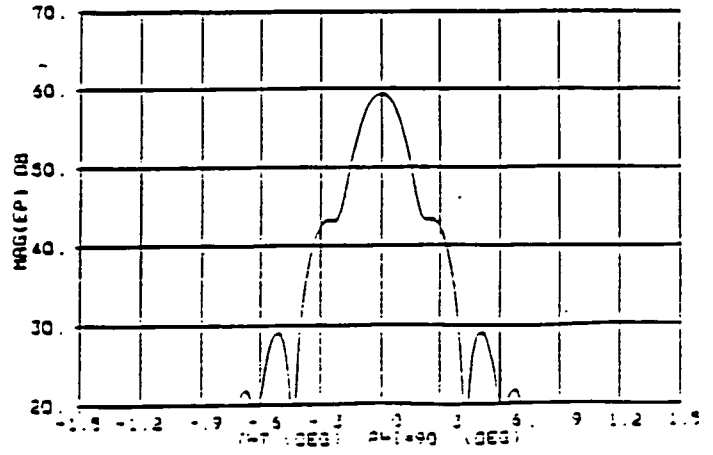
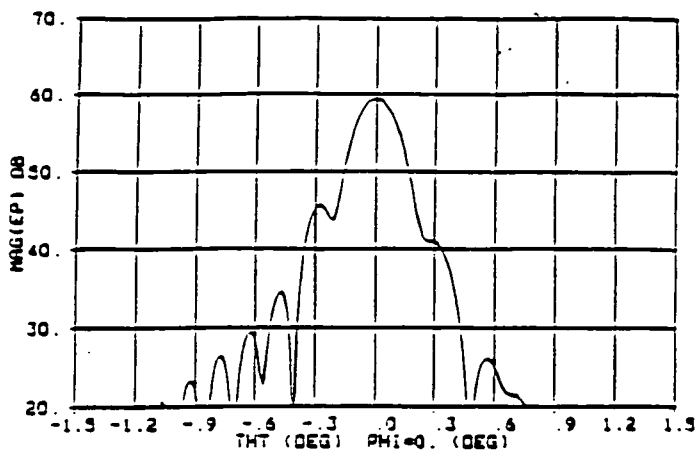
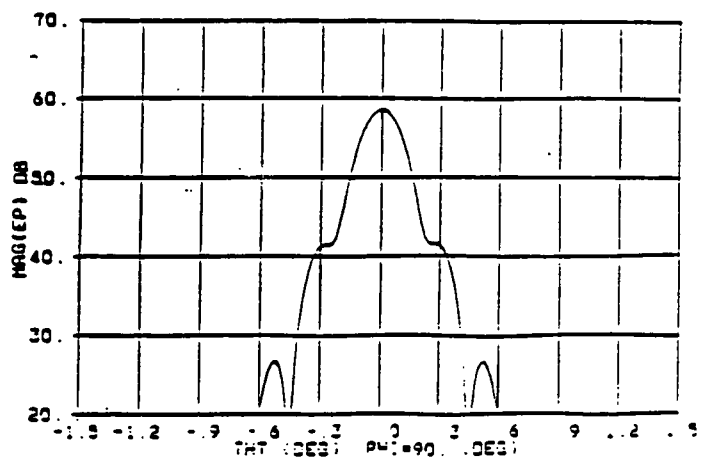
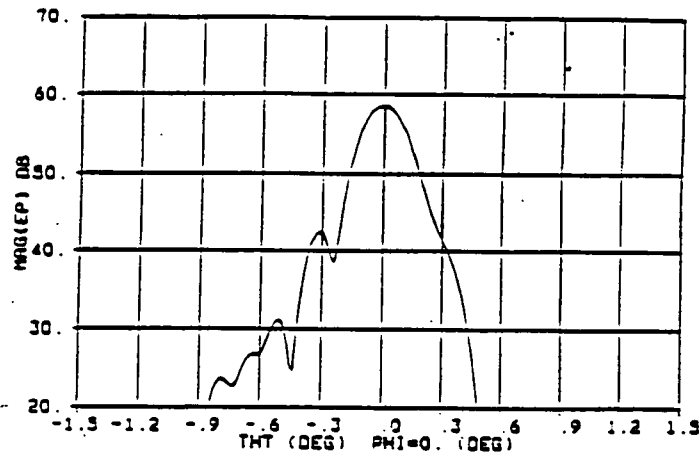


Figure 5. Calculated Patterns of symmetric spherical reflector with 1, 7, and 19 element feed arrays. Scan angle: 0°

YRS/KA-BAND 1-E SPHERICAL 3.5 DEG BEAM



YRS/KA-BAND 7-E SPHERICAL 3.5 DEG BEAM



YRS/KA-BAND 19-E SPHERICAL 3.5 DEG BEAM

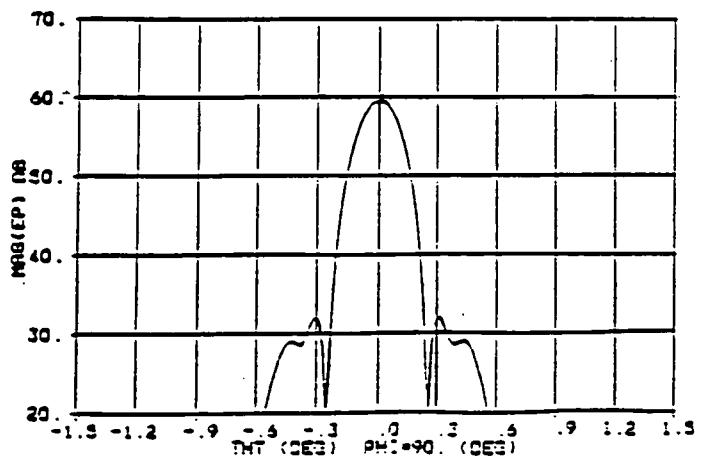
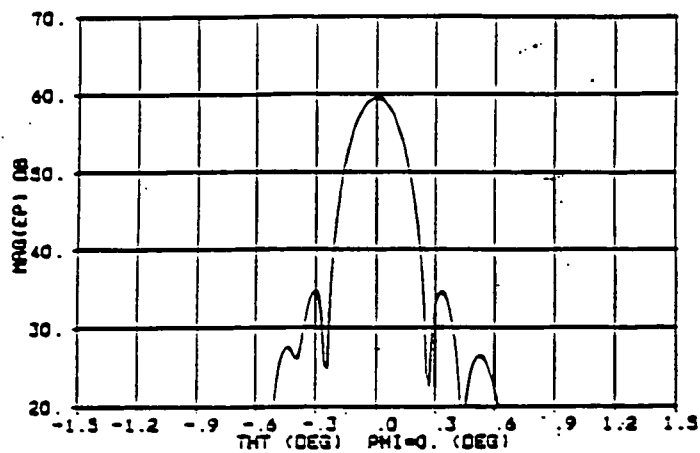


Figure 6. Calculated Patterns of symmetric spherical reflector with 1,7, and 19 element feed arrays. Scan Angle: 3.5°

Table 1. Summary of pattern calculations for Parabolic and Spherical reflectors with feed arrays.

Feed Geometry	Beam Direction	Symmetric Parabolic Reflector			Symmetric Spherical Reflector		
		Patterns	Directivity dB	Sidelobes dB	Patterns	Directivity dB	Sidelobes dB
1-Element	0°	Figures 3-a,b	60.88	< -30	Figures 5-a,b	60.19	< -17
7-Elements	0°	Figures 3-c,d	59.87	< -38	Figures 5-c,d	59.17	< -18
19-Elements	0°	Figures 3-e,f	60.06	< -27	Figures 5-e,f	59.90	< -27
1-Element	3.5°	Figures 4-a,b	59.30	< -13	Figures 6-a,b	59.49	< -14
7-Elements	3.5°	Figures 4-c,d	58.90	< -13	Figures 6-c,d	58.68	< -15
19-Elements	3.5°	Figures 4-e,f	59.77	< -25	Figures 6-e,f	59.63	< -25